Part II

Switchgear Assemblies and Captive (Emergency) Power Generation

13

Switchgear and controlgear assemblies

Contents

13.1 Application

These assemblies (HV or LV) are fitted with switching devices (breakers, switches, fuse switches and contactors etc.), control and measuring instruments, indicating, regulating and protective devices to transform the assemblies into composite units, called control centres to perform a number of functions in the field of distribution and control of electrical power. Some of these functions may be one or more of the following:

1 To control, regulate and protect a generator and its auxiliaries in a power station.
2 To control, regulate and protect the conversion, when necessary, from one voltage to another, in a generating station, a switchyard or a sub-station for the purpose of further transmission or distribution of power.
3 Transmission of power.
4 Distribution of power.

On design aspects our present thrust is more on LV switchgear and control gear assemblies being used the most. The basic idea of adopting to such a control system is to broadly accomplish the following in normal operation:

1 To have ease of operation and control a group of load or control points from one common location.
2 To monitor system operations for better co-ordination between the various feeders and rapid control of the feeders.
3 To provide a sequential operation when required between the various feeders or to have an electrical interlocking scheme between them. For a general idea refer to Figure 13.51, illustrating a typical sequential scheme showing electrical interlocking between the various feeders for an air-conditioning plant.

Thus the basic purpose of a centralized power or auxiliary control system is to achieve in service:

- Ease of operation and control
- More flexibility
- Ease of testing the electrical installation
- Ease of checking the control scheme, if any, on no-load before commencing the process.
- More safety
- More reliability

13.2 Types of assemblies

Depending upon their application, a switchgear or a controlgear assembly can be one of the following types:

1 Open Type This type of assembly is without an enclosure, as used in an outdoor switchyard or as mounted on a pole, such as a gang-operated switch.

2 Metal enclosed type This type of assembly is completely enclosed on all sides by sheet metal except for the operating handles, knobs, instruments and inspection windows. The more conventional of them in use on an LV system are discussed below.

13.3 Conventional types of switchgear and controlgear assemblies

Depending upon their application, these may have one of the following construction:

Switchgear assemblies

1 Fixed type
Industrial type
Cubicle type

2 Draw-out type

Semi-draw-out type, and
Fully draw-out type

3 Controlgear assemblies

13.3.1 Fixed-type construction

In a fixed construction, all the feeders in the switchboard, feeding the various load points, are securely mounted in the assembly and rigidly connected to the main bus. In the event of a fault in one feeder on the bus side, a shutdown of the entire switchboard may be required. A process industry or critical loads can ill-afford such an arrangement. However, since this is the most cost-effective switchboard, it is also the most common type and is used extensively. It also suits all applications, except a process industry or critical loads, which may not be able to afford a total shutdown or prolonged down-time in the event of a fault. In such cases a draw-out type switchboard will be a better choice as discussed ahead. A fixed-type construction may further be classified as follows.

Industrial-type construction

In this construction there is a common bus that runs horizontally and is mounted on vertical floor structures. The feeders are mounted above and below this busbar chamber, as shown in Figure 13.1. Since there are only two feeders in a vertical plane, these switchboards occupy a sizeable floor space, but they are rugged and easy to handle. They are good for very hard use such as construction power – i.e. the temporary power required during the construction period of a project – and have to weather severe climatic and dusty conditions. It is possible to construct them in a cast iron enclosure making them suitable for extremely humid and chemically aggressive areas and also for areas that are fire-prone. The use of such assemblies is now rare, due to the availability of better cubicle designs.

Cubicle-type construction

This is in the form of a sheet metal housing, compact in design and elegant in appearance. The feeders are now mounted one above the other up to a permissible height at which the operator can easily operate. It thus makes an optimum utilization of the vertical space and saves on floor area. They can be further classified as follows:

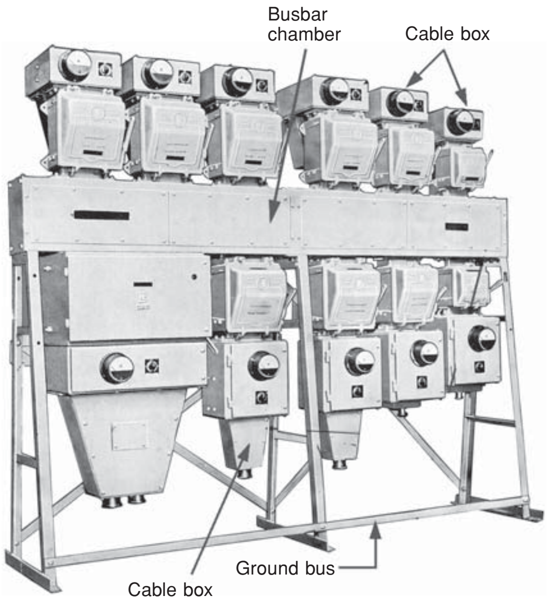


Figure 13.1 A typical industrial type power distribution board

- **Non-compartmentalized type** In this type a group of feeders are housed in one enclosure, and attending on one would mean an exposure to the others (Figure 13.2). Typical example is distribution boards (DBs).

Distribution boards (DBs)

These are comparatively smaller assemblies and distribute power to the utilities of an installation, which can be an industrial, a commercial or a residential complex. The utilities may be one or more of the following essential services:

- Lighting loads
- Cooling and heating loads
- Water supplies (pump sets)
- Fire fighting (pump sets)
- Lifts and escalators
- Welding sockets etc. for future maintenance of the installation.

A DB becomes larger when it serves a residential colony, a multi-storey building or a shopping complex where the main loads are of utilities only.

Figure 13.2 A non-compartmentalized distribution board

- **Compartmentalized type** In this type each feeder is housed in a separate compartment (module) of its own and attending on one would limit the exposure only to that unit. In this construction a fault, particularly of the nature of a short-circuit, will be contained and localized only to the faulty feeder, without spreading to the nearby feeders. This is an economical and most used construction of switchgear assemblies for light and power distribution and motor controls. When feeders of an assembly are mostly for motor controls, these assemblies are referred to as motor control contres (MCCs). Figure 13.3 shows one such distribution board.

Figure 13.3 A typical cubicle-type fully compartmentalized power distribution board

These assemblies may be further classified into single or double-front assemblies. In double-front, they may be without a maintenance gallery as shown in Figure 13.4, or in a duplex design, with a maintenance gallery between the front and rear rows of panels to provide easy access at the back of the feeders, as shown in Figure 13.5.

In the following text, although we have tried to cover the types of switchgear assemblies mentioned above, more details have been provided for assemblies that relate to a power-generating station, an industry, or installations where use of an electric drive is more common and may require more care. The design of components and devices mounted in a switchgear or a controlgear assembly is beyond the scope of this book. The different types of LV and HV interrupting devices, particularly breakers, being more intricate of them are, however, discussed in Chapter 19. Passing references have been provided in Chapter 12 for common types of switching and protective devices.

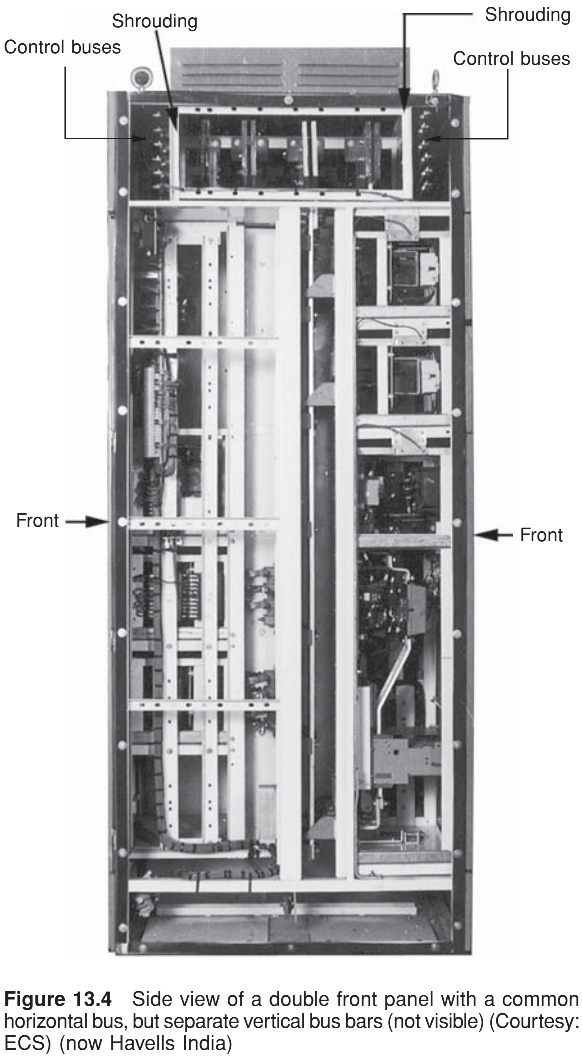


Figure 13.4 Side view of a double front panel with a common horizontal bus, but separate vertical bus bars (not visible) (Courtesy: ECS) (now Havells India)

13.3.2 Draw-out construction

In this construction each feeder is mounted on a separate withdrawable chassis. In the event of regular maintenance or repairs, they can be swiftly racked-out or racked-in to their modules without disconnecting the incoming or outgoing power connections. The control terminals may or may not be withdrawable without disconnecting the control terminals depending on whether the modules are fully draw-out or semi-draw-out type. The modules of identical types can also be easily interchanged and defective modules replaced by spare modules in the event of a fault. Down-time is now low. This arrangement is therefore recommended for all critical installations that require an uninterrupted power supply and cannot afford down-time during operation. It is most suited for installations such as at power stations, refineries, petrochemical plants, fertilizers, and similar process plants. Similarly, hospitals, airports, railways, etc. are also such critical areas that may experience chaos due to a disruption of utilities unless the normal supply is restored swiftly. In such places draw-out construction is more appropriate.

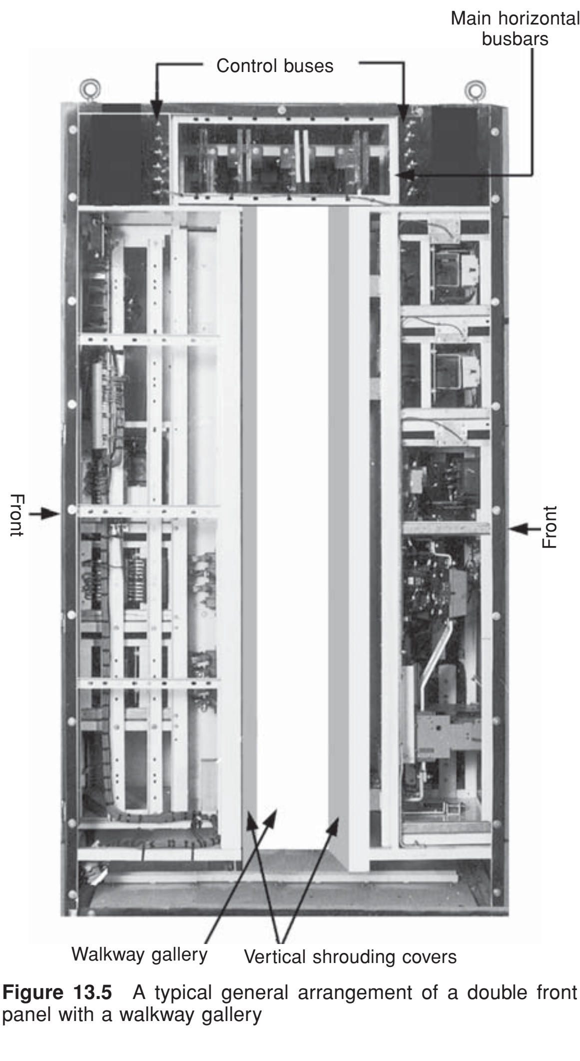
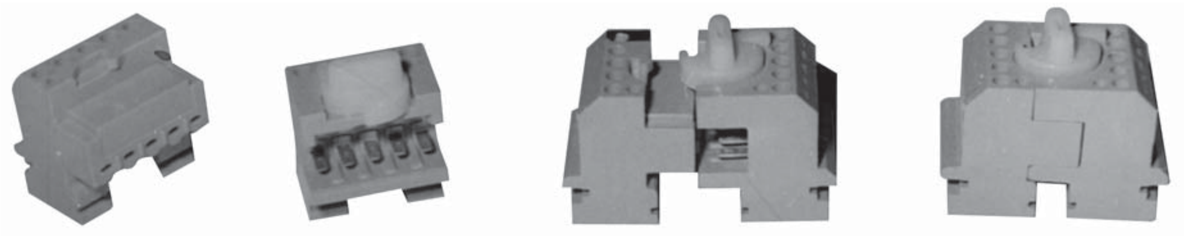
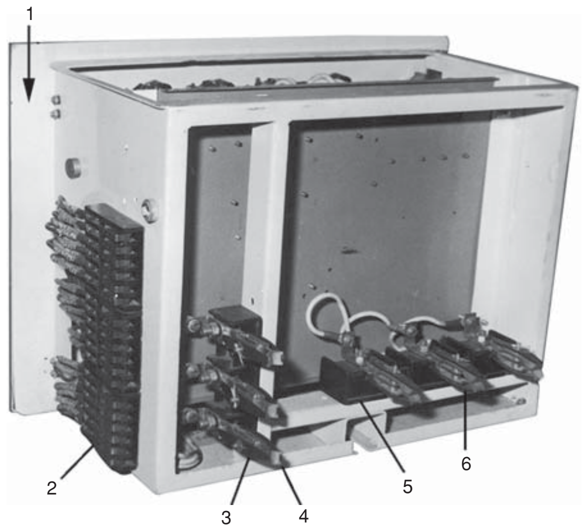


Figure 13.5 A typical general arrangement of a double front panel with a walkway gallery



Female portion Male portion Terminals disengaged Terminals engaged

Figure 13.6(a) Typical plug-in-type terminals



1. Trolley
2. Auxiliary contacts (sliding type)
3. Outgoing tulip type power contacts (female)
4. Outgoing power contacts (male)
5. Insulator
6. Incoming tulip type power contacts (female)

Figure 13.6(b) Rear view of a withdrawable chassis illustrating power and auxiliary contact details

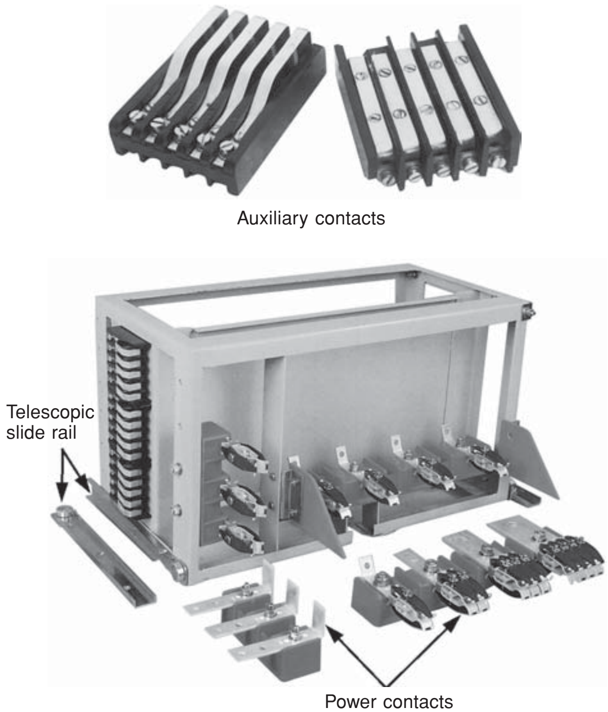


Figure 13.6(c) Draw-out power and auxiliary (control) contacts (Courtesy: Vinayak Corp.)

A draw-out assembly can be designed only in a cubicle construction and is totally compartmentalized. The two types of draw-out constructions noted above can be broadly described as follows.

Semi-draw-out type

In this design the incoming and outgoing power contacts are of the draw-out type, but the control terminals are the plug-in type. (For plug-in type terminals see Figure 13.6(a)). The plug-in contacts of the control terminal assembly are wired and left loose in the moving trolley, and are engaged manually with the fixed contacts mounted on the frame, after the trolley is racked-in and seated in its place. Similarly, the control terminals are to be disengaged manually first, when the trolley is to be drawn out.

Such a construction is cumbersome and requires utmost caution to ensure that the terminals are properly disengaged before the trolley is racked-out. Otherwise it may pull the wires and snap the connections and result in a major repair. It is also possible that after racking-in, due to human error, the operator may slip to engage the terminals at the first attempt and may have to do it at a second attempt, adding to the down-time, while energizing or replacing a faulty trolley, eventually defeating the purpose of a draw-out system. Usually therefore only fully draw-out construction is practised.

Fully draw-out type

In this construction the control terminals are of the sliding type (Figures 13.6(b) and (c)). The moving contacts are mounted on the trolley while the fixed matching contacts are mounted on the panel frame. These contacts engage or disengage automatically when the trolley is racked-in or racked-out of the module respectively. This type of construction eliminates the element of human error and reduces racking time. The trolley can now be replaced swiftly with a healthy trolley in the least possible down-time. Figures 13.7(a), (b) and (c) show a few such constructions illustrating different module and door designs as practised by different manufacturers. Figures 13.8(a) and (b) illustrate some more features of a draw-out MCC.

The cubicle type assemblies other than DBs discussed above are commonly used in the following forms.

1. Motor control centres (MCCs)

They receive power from the PCC and feed it to a number of load points, the majority of them being motors operating on an electrical installation or a process line.

When there is only one process line and one MCC alone is adequate to control the entire process, it is possible to combine the PCC and the MCC into one unit to save on space and cost. The assembly may now be called a PMCC (power-cum-motor control centre).

2. Power control centres (PCCs)

They may receive power from one or more sources of supplies and distribute them to different load centres, which may be a motor control centre (MCC) or a distribution

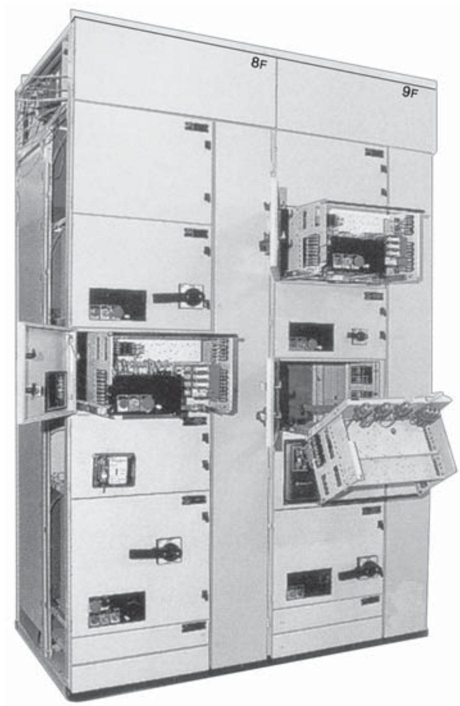


Figure 13.7(b) Another design of draw-out MCC (Courtesy: L&T)

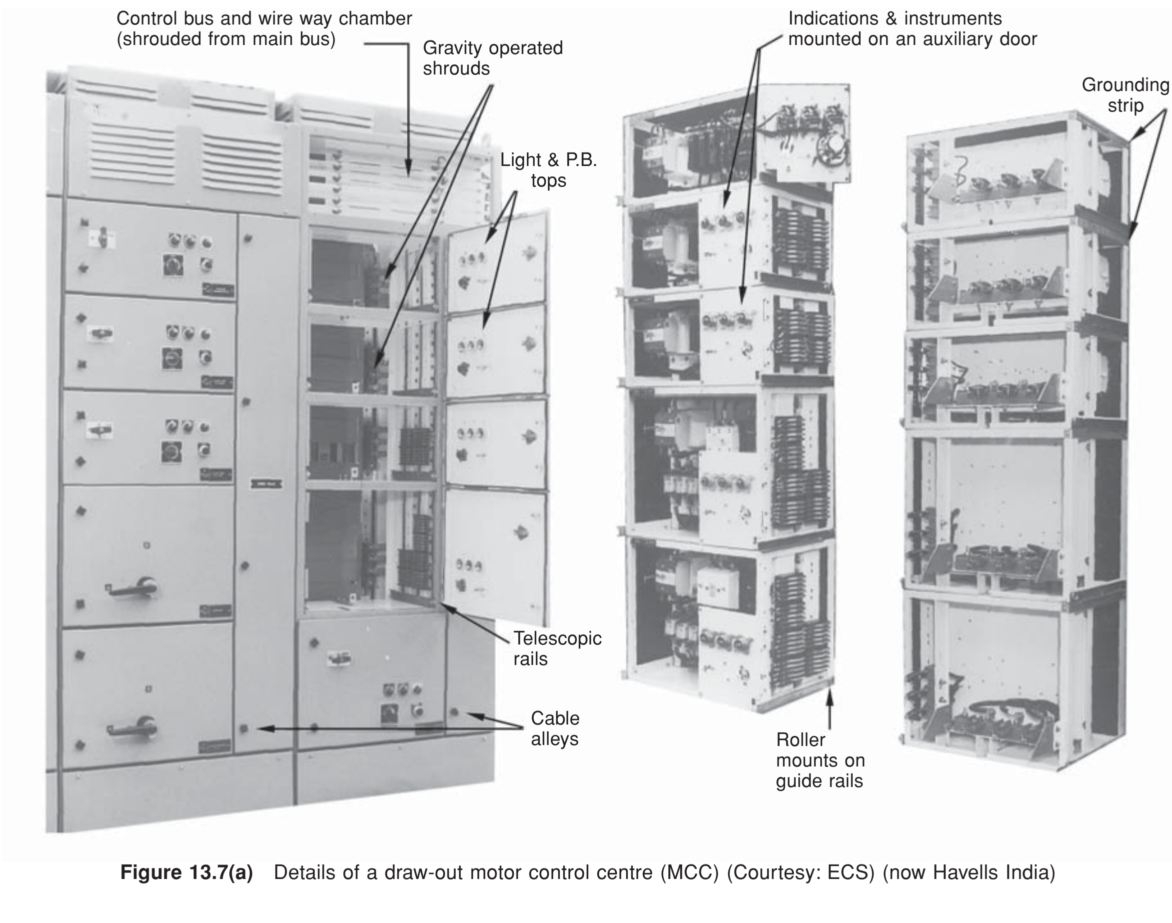


Figure 13.7(a) Details of a draw-out motor control centre (MCC) (Courtesy: ECS) (now Havells India)

Figure 13.7(c) Draw-out MCC with openings in doors to seat the auxiliary doors (Courtesy: Atoz Power Systems)

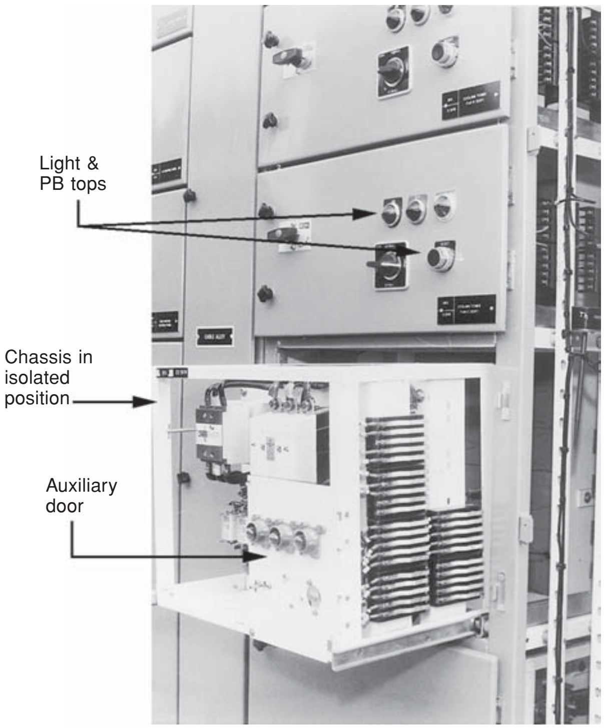
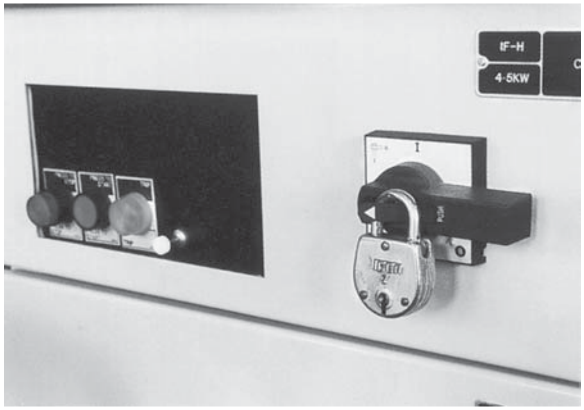
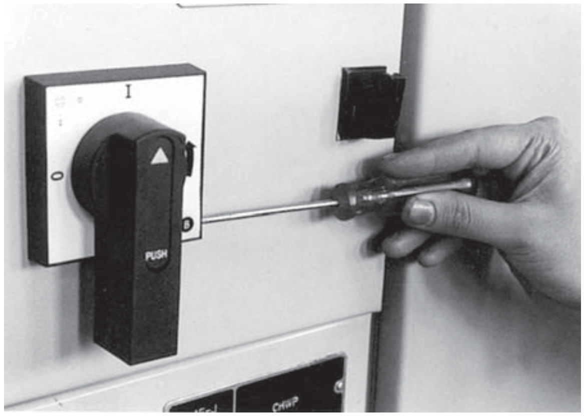


Figure 13.8(a) Part view of a typical fully draw-out type motor control centre (Courtesy: ECS) (now Havells India)

board (DB). They therefore comprise larger ratings of feeders compared to the feeders in an MCC or a DB. Figure 13.9(a) shows a typical power control centre with ACBs and protection relays. Depending on the rating and application of PCC a part of it may be draw-out (such as draw-out ACB feeders) and part of it may be fixed type (such as fixed SFU and MCCB feeders).



Padlocking of switch



Door interlock defeat facility

Figure 13.8(b) Padlocking and defeat interlocking facilities

13.3.3 Intelligent switchboards

With the availability of new generation microprocessor based relays and electronic releases (IEDs) for all kinds of breakers Sections 13.5.2 and 19.5.3 a whole switchboard can now be made intelligent like a static drive noted in Section 6.7.4(5). They can supervise and control remotely the parameters of various feeders and thus ease on complexities, achieve low downtimes, controlled operations and better efficiency. By doing continual reactive power management, switching-off feeders operating at no-load, rationalizing loads connected to different sources of supplies and providing required management input support, the intelligent equipment and devices can play a vital role in contributing towards energy saving also. Intelligent boards can monitor and control the power system locally via a laptop computer (PC) and a keyboard. Using telemetry softwares (communication protocols) and media they can be made to monitor and continually improve a process line or execute power management activities from a remote control station.

To form specifications of intelligent switchboards one may refer to the SCADA system Section 24.11 for the

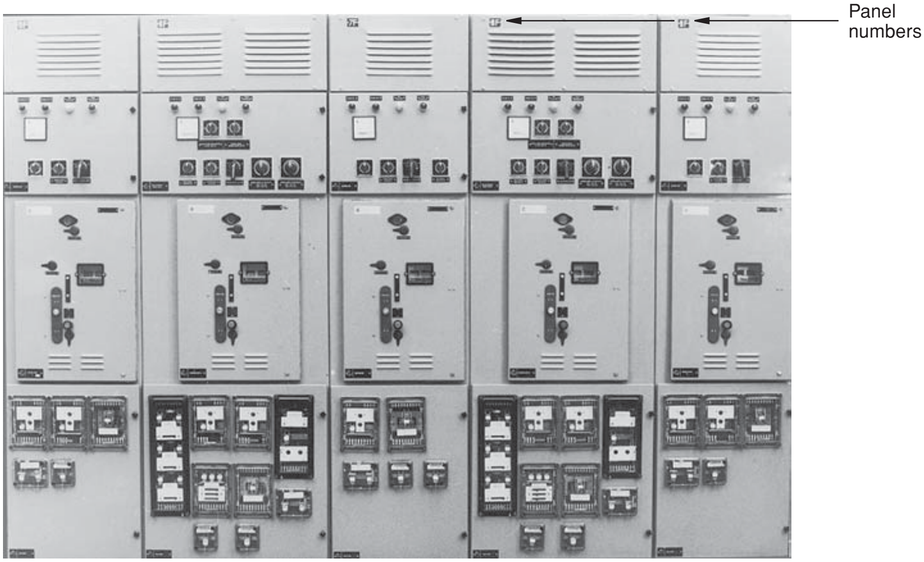


Figure 13.9(a) A typical cubicle-type power control centre (Courtesy: ECS) (now Havells India)

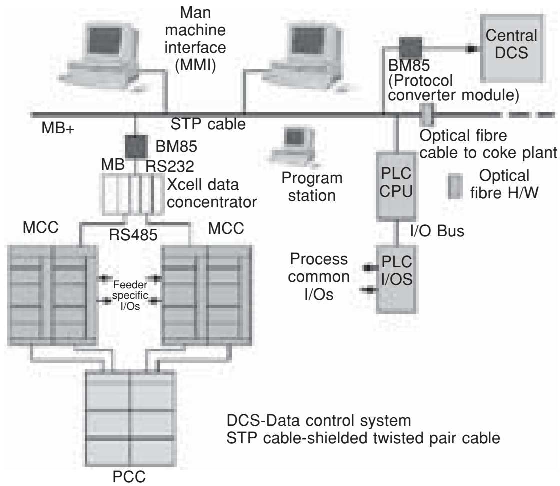


Figure 13.9(b) Typical layout of a switch room with remote control station at Tata Steel (Courtesy: Larsen & Toubro)

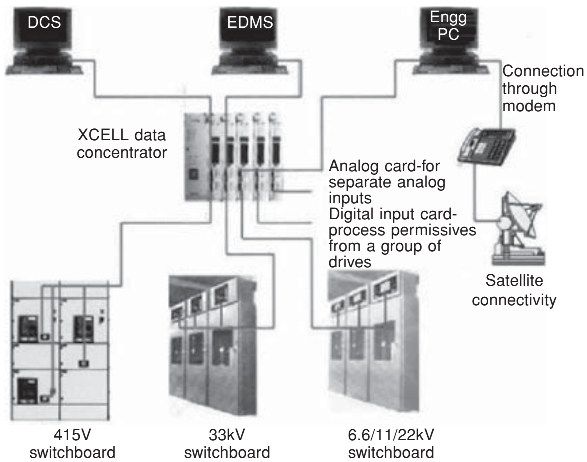


Figure 13.9(c) Application of intelligent switchboards for remote monitoring and control for total power automation (Courtesy: Larsen & Toubro)

utilities, functions and controls that these switchboards can be made to perform. For the available telemetry softwares and hardwares see Section 24.11.5. The remaining specifications shall remain same as for standard assemblies incorporating IEDs in place of analogue metering and protection devices. The modern practice of many vital installations, power systems and process lines is to go in for intelligent switchboards and this practice is on the rise. A typical layout of a switch room for a process industry with one PCC and two MCCs and remote control station is illustrated in Figure 13.9(b). The application of such switchboards in real time remote monitoring and control of a complete power system to achieving a total automation is illustrated in Figure 13.9(c). The system automation shall comprise the following.

Intelligent electronic devices (IEDs)

For control, protection, metering of individual feeders and communication at different levels of switchgears in the system. The power system can be a combination of LV, MV and HV switchgears.

Data concentrator when required

It consists of a power supply unit and communication processor cards. It collects the data from various IEDs and integrates them with high level automation like DCS(data control system), ECS(electrical control system), EDMS (energy management distribution system) and engineering PC. It can also carry process data for a group of drives, load points and separate analog inputs in independent cards.

Man machine interface (MMI)

It is a supervisory software based in the engineering PC for monitoring the entire power system from the remote control station. MMI provides an interface between the PCs located in the operator room and the IEDs located in the switchboards at the switch room. It is user-friendly software and can be configured to carry out the operational needs.

Salient features

- General arrangement drawing and bill of material on the screen
- Single line diagram giving feeder status
- Feeder control
- Parameter display
- Status of digital inputs
- Updated alarm list and alarm management
- Fault record extraction
- Status of faults with reset facility
- Data archiving and trending of analog parameters including historical trend
- Online relay setting with password protection
- Supervision & diagnostics

Special features

- **Modern connectivity** The communication signals/information can be transmitted anywhere in the world through modem connectivity.
- **Global positioning system** (GPS) It synchronises the clock in the IEDs with the GPS satellite. Using data transmitted by the GPS satellites, the IEDs synchronise their time to the resolution of milliseconds irrespective of their position on the globe. See Figure 24.39 for more clarity.
- **Single line diagram** The board-wise single line diagram displays online status of breakers/feeders through change in colour. The diagram also shows the various IEDs connected in the circuit. On clicking these IEDs, the operator can navigate through the various screens displaying information communicated by the IEDs. See similar representation in Figure 24.34(i).
- **Parameters** This screen provides values of various parameters communicated by the IED of a particular feeder. Parameters include three-phase current, ground current, voltage, power, power-factor, thermal capacity, number of operations, etc. These can be displayed either as analog values or with graphical representation. See similar representation in Figure 24.34(ii)
- **Trend** MMI also enables online monitoring of various trends for parameters like current, voltage, power, power factor, peak demand etc, as useful for energy management. See similar representation in Figure 24.34(iii).

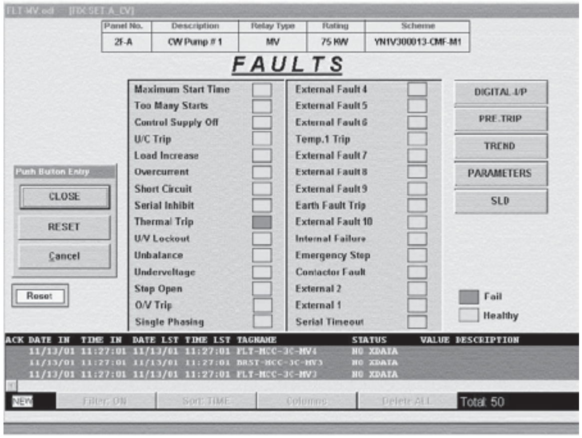


Figure 13.9(d) Typical display of faults (Courtesy: L&T)

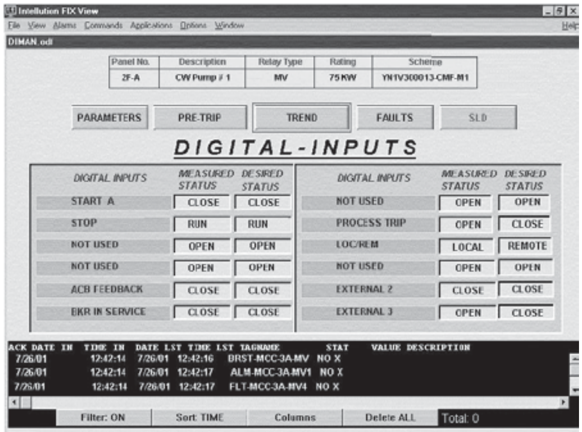


Figure 13.9(e) Typical display of individual inputs (Courtesy: L&T)

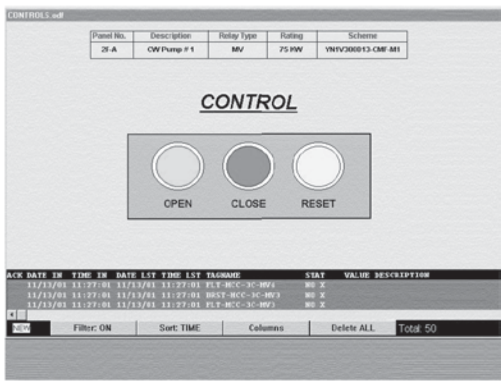


Figure 13.9(f) Control buttons (Courtesy: L&T)

Man machine interface (MMI)

- **Faults** The fault screen lists down all protections supported by IEDs and displays the status if a fault exists, through change in colour. Facility to reset the fault from the PC with password protection is possible. See Figure 13.9(d)
- **Digital inputs** This screen displays status of individual digital inputs. A comparison of desired status of stored

data with actual status helps in scheme diagnostics. See Figure 13.9(e)

- **Controls** Controls can be provided with password protection. Three buttons start, stop and reset enable the operator exercise control on the respective feeder. See Figure 13.9(f)
- **Relay settings** MMI facilitates online change in settings of the IEDs through serial link. Password-protected relay settings are read and displayed on the screen. The required change is set and relayed to the specified IED only by an authorized user. Screen is developed to assist setting of IEDs without referring to the IED manual. See Figure 13.9(g)
- **Pre-trip values** Fault diagnosis can be assisted by capturing the values prior to tripping from the IED. These pre-trip values are also captured and made available. See Figure 13.9(h)
- **Historical trend** To further assist fault diagnostics and find out the exact behaviour of the load. Historical values of the various parameters being monitored are plotted to show historical trend. This also helps in identifying the exact time of the fault.
- **Alarms** A mini alarm screen displaying the last 3 alarms appears across all screens, prompting the supervisor to respond if required. Details of all alarms can be viewed by going to the alarm screen. See similar representation in Figure 24.34(iv).

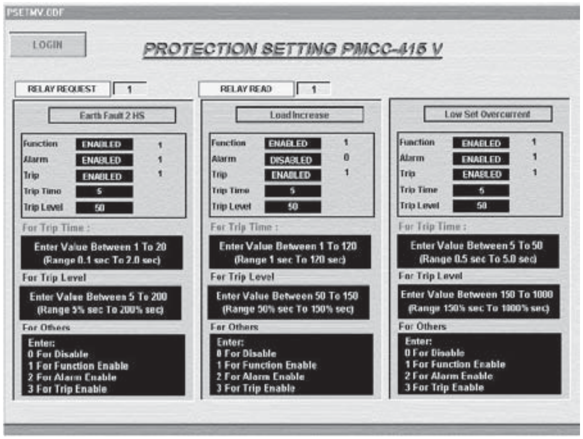


Figure 13.9(g) Typical display of relay settings (Courtesy: L&T)

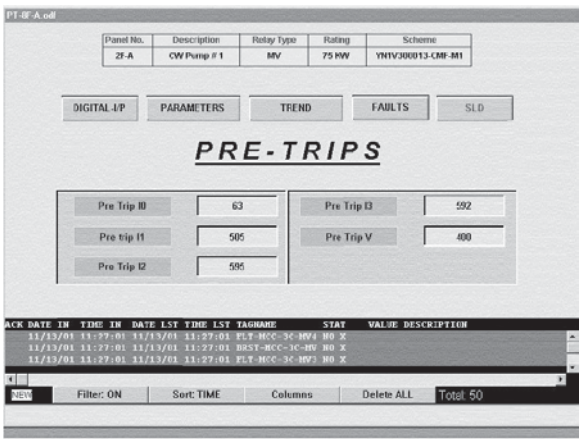


Figure 13.9(h) Typical display of pre-trip values (Courtesy: L&T)

13.3.4 Compact switchgear assemblies

To save on space and energy, leading manufacturers supported by their extensive R&D facilities have produced new generation compact switchgear components like contactors, relays, SFUs, MCCBs, MPCBs and ACBs. Besides being space saver they consume low I^2R losses due to shorter current carrying paths. Most components are totally enclosed having shrouded terminals and can be placed side-by-side in a common compartment and interconnected through a common, compact and encapsulated busbar system to save on space, energy and cost (for compact busbars see Section 28.2.6). For dimensions and extent of energy saving one may consult the manufacturer. Fig. 13.9(i) shows a few such components.

13.3.5 Controlgear assemblies (for controls and monitoring of a process)

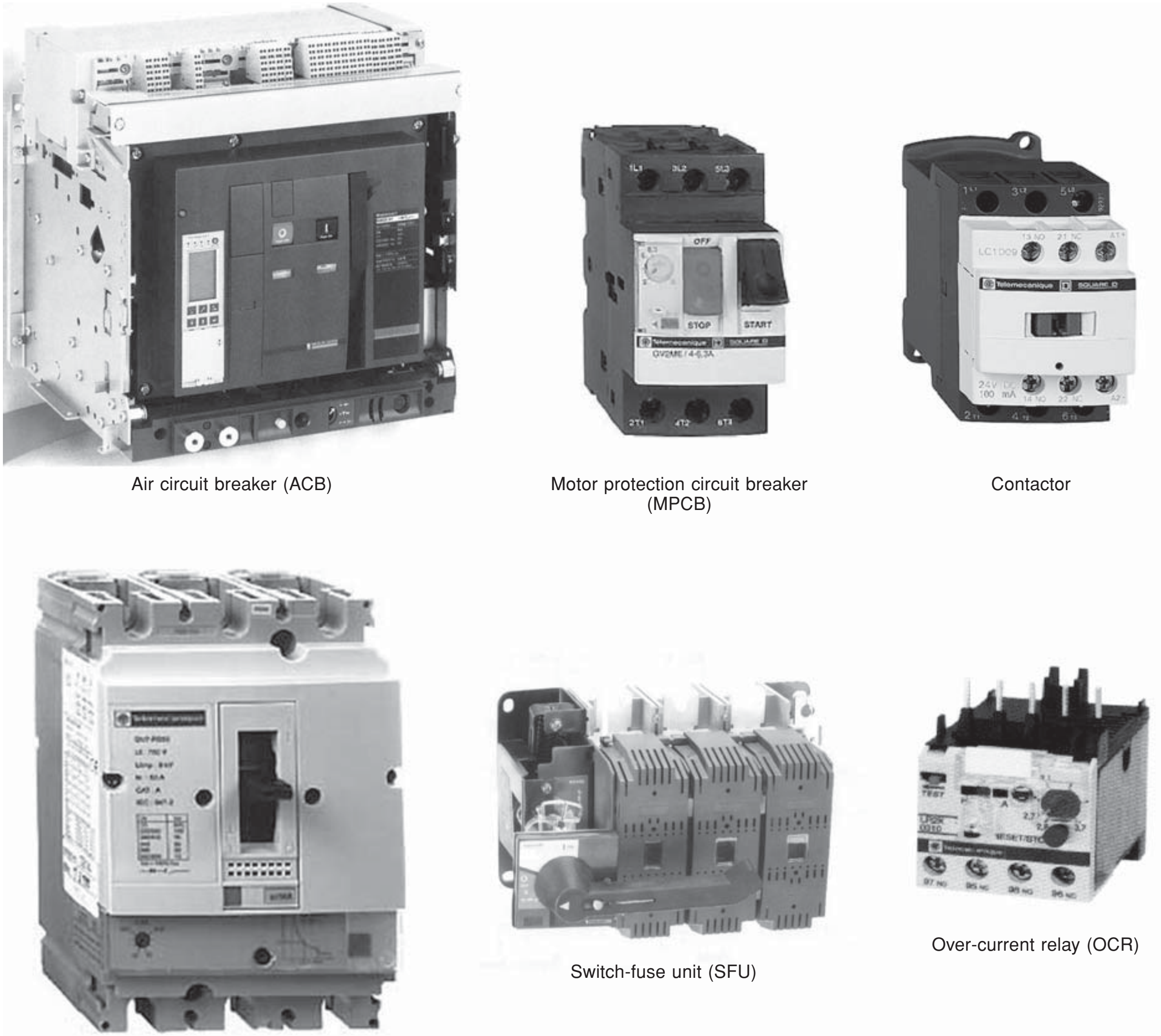
Such control assemblies are designed to programme the control of a process line and also to monitor its performance through audiovisual indications or a trip command. They receive control cables carrying the different process signals from the MCC, drives and the process control devices (such as temperature, pressure, flow and speed-measuring devices) to actuate the required audiovisual indications or a trip command when the process-operating parameters fluctuate by more than the predefined limits. They operate at control voltage and do not handle any power device. Depending upon the application, they can be termed a control panel (CP), a mimic panel or a relay and control panel. Figures 13.10 and 13.11 illustrate a few such assemblies. (Also refer to Section 16.8 and Figure 16.11). All the above assemblies are floor mounted and free standing, except those that are too small and which can be mounted on a wall or fixed in a recess.

13.3.6 PLC*-based control panels

Conventional method to activate controls has been through auxiliary relays (contactors). The sensing instruments that are located at the various strategic locations of a process line or on the machine feeding the line sense the actual operating conditions continuously and give a signal through its auxiliary relay in the event of an error beyond permissible limits.

In a process industry (e.g. chemical, fertilizer, cement, paper, textile, tyre or petrochemicals) such process controls are numerous, and to closely monitor and control each through the conventional method is arduous and may delay the corrective action besides imposing many other constraints. They also require cumbersome, excessive and complex wiring and a very large control panel, as

*PLC – Programmable logic controller (a registered trademark of Allen Bradley Co. Inc., USA).



Air circuit breaker (ACB)

Motor protection circuit breaker (MPCB)

Contactor

Moulded case circuit breaker (MCCB)

Switch-fuse unit (SFU)

Over-current relay (OCR)

Figure 13.9(i) New generation compact switchgear components (Courtesy: Schneider Electric)

shown in Figure 13.11, for a small process line. There will also be limitations in terms of accuracy besides response time, control and maintenance problems. Thus this method is not suited to critical applications. A relay may have to activate another before it activates the correction and regulates the machine feeding the process line, hence adding to more delay. A contactor operation, particularly, introduces an element of time delay (5 to 10 ms each relay) in executing correction because of its inherent closing and interrupting times. Also there may be a number of these operating one after another in tandem before correcting the process. The time delay may affect the quality of process and may not be warranted. With advances in solid-state technology control and feedback devices can now be in the form of programmable logic controllers (PLCs), which respond instantly and can be programmed in a discrete way, to suit any process needs.

With the application of PLCs and numerical relays any kind of process control and automation, can be achieved, extending all possible supervision activities such as monitoring, control, protection and metering even data transfer and communication of a critical feeder/machine or a process line from one point and through one source to a centralized monitoring and control station. All control panels and switchgear power systems supported with such microprocessors and other intelligent electronic devices (IEDs) can be termed as intelligent control and power switchgears (see Section 13.3.3). The back-up software can be programmed to the desired needs. The application of such automation is gradually becoming the order of the day for all important industrial installations, process lines or critical individual machines and feeder circuits.

A controller is extremely small and can perform the duties of hundreds of such relays and requires only a

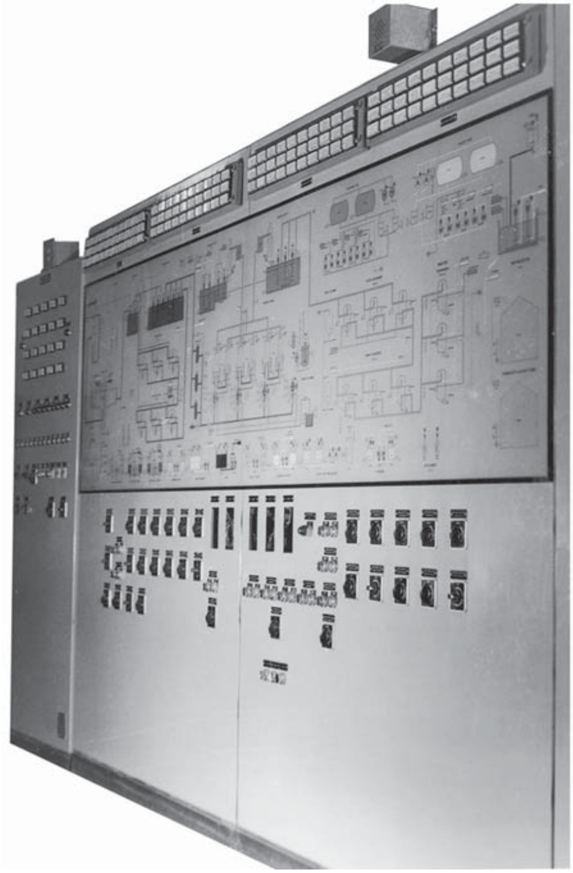


Figure 13.10 A typical mimic-cum-process control panel (Courtesy: ECS) (now Havells India)

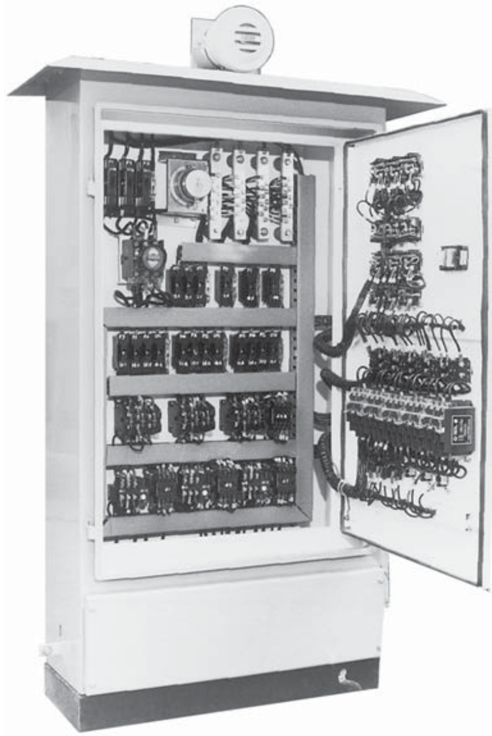


Figure 13.11 A non-compartmentalized outdoor-type control panel

small space for mounting. It is wired internally and eliminates all external wiring. There are no moving contacts and hence no phenomenon of operating time, contact arcing, or wear and tear of contacts.

A logical controller is a solid-state *digitally operated* control device which can be programmed to follow a set of instructions such as logic sequencing, timing, counting and arithmetic analysis through digital or analogue input and output signals to respond to the different process requirements. These may be regulating the speed of the motor to perform inching duties as when a loader crane or an elevator is required to adjust its hoisting height precisely at different loading stations or to adjust the movement of a moving platform of a machine tool. Figure 6.49 illustrates a typical process line. It can also perform data handling and diagnostic activities by storing data and messages and also give signals to activate, adjust or stop a process. A logical controller therefore is an intelligent electronic device (IED) and can replace a relay-based circuit more efficiently. It also offers many more operational facilities and ease of handling than a relay, and all this instantly, without causing a time delay. Indeed a device leading to total automaton (also see SCADA Section 24.11). PLCs are also employed as data acquisition and control devices for substation elements that are not equipped with microprocessor based protective relays.

Details of PLCs

It is a small computer containing three main sections:

1. **Central processing unit (CPU)** This is in the form of a micro controller and can be called the brain of the PLC. It computes and analyses the various data fed into it. It acts like a comparator and makes decisions on the corrective action necessary to fulfil process needs according to the instructions received from the program stored in the memory and generates the output commands.
2. **Memory unit** This is the unit that stores the data and the messages and the diagnostic information. It stores all the data that defines the process to help the CPU act logically and also stores diagnostic information. It is a part of a computer that contains arithmetical and logical controls and internal memory and programming devices. The unit receives inputs (temperature, pressure, speed or any information which may form a part of the process) from the system. It then compares it with the reference data, which is already programmed into its memory module, analyses it and then sends out a corrective signal to the process line devices, controlling temperature, pressure, speed or any other parameter. Or it can be employed in inverter logistics, when it is being used for the control of the drive itself. Figure 13.12 illustrates a basic logical scheme.
3. **Input and output interface** This is the interface between the controlling devices and the processor.

The input/output (I/O) unit receives signals from the input devices and transmits output action signals to the controlling devices.

Note
A separate unit is used for programming and editing (e.g. a hand-held programmer or a computer). For on-line editing, keyboards are used. For on-line monitoring, a PLC is interfaced with a computer and special software.

A logical controller is thus a more effective method of replacing the auxiliary relays and is capable of performing many more functions instantly.

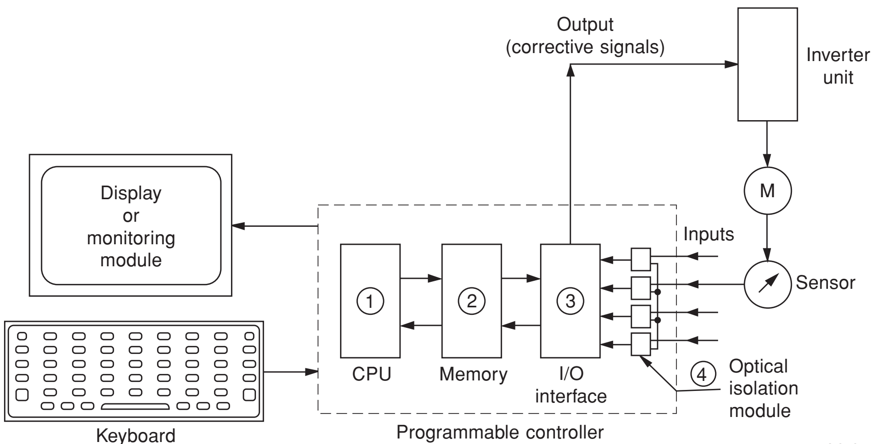
A process requiring accurate and instant speed controls must adopt static motor controls, described in Section 6.2, and their control schemes must be activated through programmable logic controllers (PLCs) discussed above.

PID (Proportional, Integrative, Derivative) control
It is a kind of feedback control algorithm. In a closed loop control scheme the PID algorithm optimizes the process of flow, temperature, pressure or any other vital process parameter through proportional, integral and differential calculation between the feedback value and the reference value.

Shielding of signals (to achieve electromagnetic compatibility (EMC) Section 23.18)

It is important to prevent the control signals from becoming corrupted by electromagnetic and electrostatic interferences (EMI) caused by the power circuits, particularly those carrying the motor currents from the machine to the power-cum-control panel housing and the PLC. During each switching sequence, the motor will draw switching currents and develop switching voltages. Even small electrostatic interference may corrupt the signals. Shielded (screened) control cables are therefore recommended for this purpose for the control panels' internal wiring, particularly between the incoming terminals and the logic controllers (PLCs), cables carrying the TG analogue or pulse encoder digital corrective signals from the field and all sensor and analog circuits. The best way to minimize electromagnetic and electrostatic interferences (EMI) is to segregate the power and control circuits through careful design and manufacture of control cabinets to give them the effect of Faraday cages.

The shield is generally a layer of copper wires in the form of a spirally wrapped screen around the control cable. It is also recommended to avoid a parallel running of power and signal control coaxial cables. Also, for each signal a separate two-core control cable must be used, since common return of different analog signals is not recommended. The shielded cables also call for a careful grounding to avoid EMI effects. A simple grounding scheme for the shielded control cables is illustrated in Figure 13.13. Similar shielding is possible with the use of fibre optic cables. For grounding procedure see Section 6.13.3.

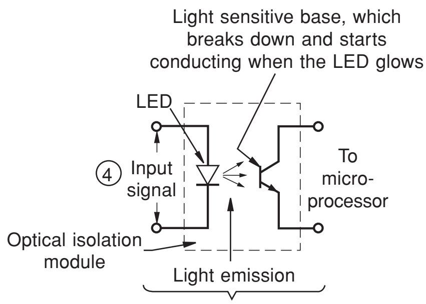


(1) CPU or micro-controller: It is a computing and analysing unit

(2) Memory module which stores the reference data diagnostics and the operating program of the process line

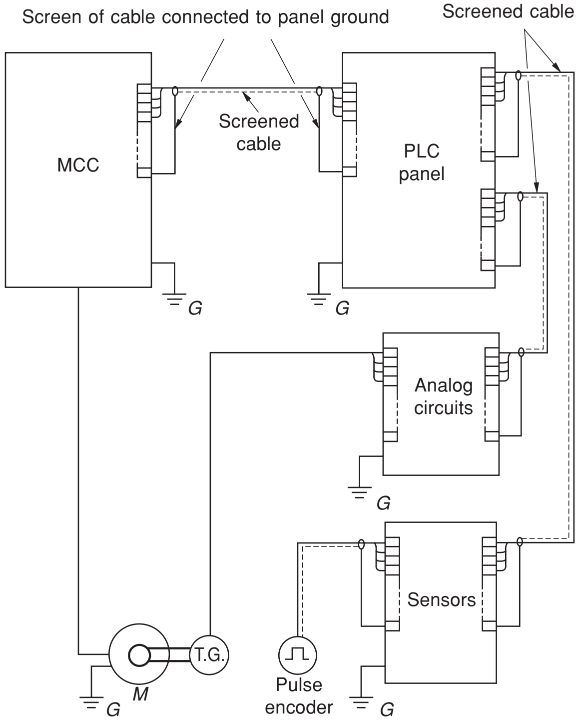
(3) Input/output interface:
It is a relaying unit to receive actual parameters from the field and relay out corrective signals

(4) A sort of electronic switch to protect the controller from control voltage spikes. They may occur because of very high control voltage (in the range of 24 to 220 V d.c.) compared to the very low voltage circuit of the microprocessor, generally in the range of 5 V d.c. or less



An optical isolation scheme
(One for each signal)

Figure 13.12 A simple representation of a programmable controller



Note It is recommended to provide isolated grounding system for electronic circuits (see Section 6.13.3).

Figure 13.13 A simple grounding scheme for the shielded control cables

13.4 Design parameters and service conditions for a switchgear assembly

13.4.1 Design parameters

A switchgear or a controlgear assembly will be designed to fulfil the following design parameters:

Rating
1 Rated voltage
2 Rated frequency
3 Rated insulation level
4 Rated continuous current rating and permissible temperature rise
5 Rated short-time current rating or fault level of a system (breaking current for an interrupting device)
6 One second or three second system
7 Rated momentary peak value of the fault current (making current for an interrupting device)

A switchgear assembly may be assigned the following ratings:

1 Rated voltage This should be chosen from Series I or Series II as shown in Table 13.1. Nominal system voltage is the normal voltage at which an equipment may usually have to perform. The maximum system voltage is the highest voltage level which the supply system may reach temporarily during operation and for which the equipment is designed.

Table 13.1 Rated voltages and frequencies for metal enclosed bus systems also applicable for switchgear assemblies

Series I		*Series II*	
Frequency: 50 or 60 Hz		*Frequency: 60 Hz*	
**Nominal system voltage*	*Rated maximum system voltage*	*Nominal system voltage*	*Rated maximum system voltage*
		(ANSI C37-20C)	
kV	*kV*	*kV*	*kV*
0.415**	0.44	0.48	0.508
0.6**	0.66	0.60	0.635
3.3	3.6	4.16	4.76
6.6	7.2	7.2	8.25
11	12	13.8	15.0
15	17.5	14.4	15.5
22	24	23.0	25.8
33	36	34.5	38.0
44	52	69.0	72.5
66	72.5	–	–

Based on IEC 60694, BS 159 and ANSI C37-20C.

–* For new voltage systems as per IEC 60038 see Introduction.
– For higher voltages – refer to Tables 13.2 and 13.3 for series I and IEC 60694 for series II.

Notes
Series I: Based on the current practices adopted by India, Europe and several other countries.
**These voltages have now been revised from 0.415 kV to 0.4 kV and from 0.6 kV to 0.69 kV as in IEC 60038. We have used 415V wherever it is referred to for an LV system as the total change over to 400 V by the user and the manufacturer may take some time. The existing installations may take still longer to change. The reader may substitute 400 V whenever needed and arrive at the modified data. Table 13.7 however, shows fault levels for a 415 as well as 400 V system.
Series II: Based on the current practices adopted in the USA and Canada.

2 Rated frequency 50 or 60 Hz (refer to Table 13.1).

3 Rated insulation level This will consist of

- Power frequency voltage withstand level, according to Section 14.3.3 and
- Impulse voltage withstand level for all LV and HV assemblies according to Sections 14.3.3 and 14.3.4.

Assigning the impulse level to an HV switchgear assembly

As discussed in Sections 17.5 and 23.5.1, an electrical network may be exposed to different voltage surges which may be internal or external. The extent of exposure of the connected equipment would determine its level of insulation. IEC 60071-1 has recommended the desired level of insulation for different system voltages and the extent of their exposure, as shown in Tables 13.2 and 13.3, for the HV switchgears installed in a distribution

Table 13.2 Standard insulation (impulse) levels for series I range I voltage systems (1 kV < V_m ≤ 245 kV)

Nominal system voltage[1] V_r kV (r.m.s.)	*Rated maximum system voltage V_m kV (r.m.s.)*	*Standard one-minute power frequency withstand voltage (phase to ground) KV* (r.m.s.)*			*Standard lightning impulse (1.2/ 50 μs) withstand voltage phase to ground** kV* (peak)*		
		List I	*List II*	*List III*	*List I*	*List II*	*List III*
3.3	3.6	10	–	–	20	40	–
6.6	7.2	20	–	–	40	60	–
11	12	28	–	–	60	75	–
15	17.5	38	–	–	75	95	–
22	24	50	–	–	95	125	–
33	36	70	–	–	145	170	–
45	52	95	–	–	250	–	–
66	72.5	140	–	–	325	–	–
–	100	150	185	–	380	450	–
110	123	185	230	–	450	550	–
132	145	230	275	–	550	650	–
150	170	275	325	–	650	750	–
220	245	360	395	460	850	950	1050

As in IEC 60071-1 and IEC 60694
Notes
* More than one lightning impulse insulation level is indicative of the extent of exposure of equipment to lightning surges. Correspondingly the power frequency withstand voltage can also be more than one.
** Lightning stress between the phases is not more than the lightning stress between a phase and the ground. For more details refer to IEC 60071-1.
[1]IEC 60071-1 has specified only V_m values. Nominal system voltage V_r are indicated based on the practices adopted by various countries and IEC 60038.
For new voltage systems as per IEC 60038 see Introduction.

Table 13.3 Standard insulation (impulse) levels for series I range II voltage systems (V_m > 245 kV)

Nominal system voltage[1] (V_r)	*Highest voltage for equipment V_m*	*Standard one-minute power frequency withstand voltage*	*Standard switching impulse (250/2500 μs) withstand voltage*			*Standard lightning impulse (1.2/50 μs) withstand voltage phase to ground[2]*
kV(r.m.s.)	*kV(r.m.s.)*	*kV(r.m.s.)[3]*	*Phase to ground kV (peak)[4]*	*Ratio to the phase to ground peak value as in IEC 60071-1*	*Phase-to-phase kV (peak)[5]*	*kV (peak)[4]*
275	300	380	750	1.50	1125	950
			850	1.50	1275	1050
330	362	450	850	1.50	1275	1050
			950	1.50	1425	1175
400	420	520	950	1.50	1425	1300
			1050	1.50	1575	1425
–	550	620	1050	1.60	1680	1425
			1175	1.50	1760	1550
–	800	830	1300	1.70	2210	1800
			1425	1.70	2420	2100

As in IEC 60071-1 and IEC 60694
Notes
[1]IEC 60071-1 has specified only V_m values. Nominal system voltages (V_r) are indicated based on the practices adopted by various countries and IEC 60038.
For new voltage systems as per IEC 60038 see Introduction
[2]Lightning stress between the phases is not more than the lightning stress between a phase and the ground. For more details refer to IEC: 60071-1.
[3]These values are applicable for
– Type tests – phase to ground
– Routine tests – phase to ground and phase to phase.
[4]More than one lightning impulse insulation level is indicative of the extent of exposure of an equipment to lightning surges.
[5]These values are meant for type tests only.

network. The recommended insulation levels will take account of the following aspects.

Indoor installations

For installations that are electrically non-exposed, internal surges and over-voltages may be caused by one or more of the following:

(a) At surge frequency

- Switching surges, as may be caused during the switching operation of an inductive circuit (Section 17.7.2) or a capacitive circuit (Section 23.5.1)
- Grounding over-voltages, as may be caused by a sudden ground fault on a phase in an isolated neutral system (Section 20.2.1)

(b) At power frequency

- Momentary over-voltages due to a sudden load rejection, which may over-speed the generator and develop higher voltages or
- Sustained over-voltages

All such installations are assigned the impulse voltages as in list I of Tables 13.2 and 13.3.

Outdoor installations

Installations that are electrically exposed to lightning are assigned the impulse voltages as in lists II or III of Table 13.2 or list II of Table 13.3, depending upon the extent of their exposure to lightning and the method of their neutral grounding.

List I

1 When the system is not directly connected to an overhead line, such as when connected through a transformer.
2 When the neutral of the system is grounded solidly or through a small impedance (Section 20.4).
3 When the system is provided with a surge protection.

List II or List III

1 When the system is connected to an overhead line.
2 When the neutral of the system is not solidly grounded.
3 When no surge protection is provided.
4 When the installation demands a high degree of security, such as in a generating station.

Note
IS 8084, however, has opted for list II for the busbar systems for all applications.

Although the rated values are based on experience and field data collected, sometimes these values may be exceeded in actual operation, due to changed service or weather conditions. It is, therefore, recommended to take cognisance of this fact and provide a surge protection to contain the surge voltages within the rated values of Tables 13.2 and 13.3. It is recommended that actual site tests be conducted on similar installations to ascertain the likely level of voltage surges that may occur during operation. To be on the safe side, it is recommended for outdoor installations, particularly, to contain the severity of the surge voltages, with the help of surge arresters, within the maximum assigned impulse voltages (BIL) of the equipment, considered in Tables 13.2 and 13.3, less the protective margins, for range I and range II voltage systems respectively.

4 Rated continuous current ratings and permissible temperature rise

The current ratings should generally be selected from series R-10 of IEC 60059 which comprises the following numbers:

1, 1.25, 1.6, 2, 2.5, 3.15, 4, 5, 6.3 and 8 etc. and their multiples in 10 e.g. for the number 1.25 the standard ratings may be; 1.25, 12.5, 125, 1250 or 12500A etc. IS 8084 has suggested the following ratings in amperes based on the above series:

100, 250, 400, 630, 800, 1250, 1600, 2000, 3150, 4000, 5000, 6300, 8000, 10000, 12500 and 15000 etc.

The temperature rise limits of the various parts of a switchgear assembly during continuous operation at the rated current must conform to the values in Tables 14.5 and 14.6.

Diversity factor

The connected load of an electrical installation is generally more than its actual maximum demand at any time. The reason is the liberal provisions made for loads that are to be used occasionally – spare feeders, maintenance power sockets and some reserve capacity available with most of the outgoing feeders. Moreover, some of the feeders may be operating under-loaded. To design a switchgear assembly, particularly for its incoming feeder and the busbar ratings, based on the connected load would be neither economical nor prudent, and the protective scheme too would under-protect such a system.

Based on experience, IEC 60439-1 has suggested a multiplying factor, known as the 'diversity factor' as noted in Table 13.4. This factor depends upon the number of outgoing circuits and is defined by the ratio of the maximum loading on a particular bus section, at any time, to the arithmetic sum of the rated currents of all the outgoing feeders on that section (Figure 13.14). This factor also helps to determine the most appropriate and economical ratings of the main equipment, such as the transformer, cables or the bus system, associated switchgear and the protective devices (Example 13.1). The values of Table 13.4 are based on a general assumption, and may vary from one installation to another depending upon the system design, the derating factors considered and any other provisions made while choosing the rating of a feeder (outlet), as noted above. It is therefore recommended that this factor be specified by the user, depending upon likely capacity utilization, to help the switchgear assembly manufacturer to design a more

Table 13.4 Conventional values of diversity factor

Number of main outlets	*Diversity factor*
2 to 3	0.9
4 to 5	0.8
6 to 9	0.7
10 and above	0.6

As in IEC 60439-1

economical busbar system. In the absence of this, the factors as indicated in Table 13.4 may be applied.

Example 13.1

Consider the power distribution system of Figure 13.14, having the following feeder details:
I/C feeder, 4000A

O/G feeders
- 1 No. 800 A = 800 A
- 7 Nos. 630 A = 4410 A and,
- 4 Nos. 400 A = 1600 A

∴ Total connected feeder load = 6810 A
and diversity factor for 12 Nos. feeders as in Table 13.4 = 0.6
∴ Maximum loading on the incoming feeder or the main busbars at any time = 6810 × 0.6
= 4086 A

Accordingly we have selected the rating of the incoming feeder as 4000 A (that should be sufficient). The maximum loading on each vertical section is worked out in Figure 13.14. These ratings of vertical busbars are when the arrangement of busbars is to individually feed each vertical row. If one common set of busbars is feeding more than one vertical section, the rating of busbars can be further economized. But one must take cognisance that too many tappings from one section of the bus may weaken the bus system.

If two sections are joined together to have a common vertical bus system, say, Sections 3 and 4, then the rating of the common bus will be:

Total connected load = 2060 + 2230
= 4290 A
Diversity factor for 8 numbers of feeders = 0.7
∴ Maximum rating = 4290 × 0.7
= 3003 A
or say = 3000 A

Section → 1	2	3	4
I/C 4000A ACB	630A	630A	800A
	630A	630A	630A
	630A	400A	400A
	630A	400A	400A

Total connected feeder load	2520A	2060A	2230A
Total connected load	←	6810A	→
Diversity factor as per Table 13.4	0.8	0.8	0.8
Maximum loading at any time	2016A	1648A	1784A
Recommended rating of busbar	2000A	1600A	1800A

Figure 13.14 Illustration of diversity factor

as against 1600 A + 1800, i.e. 3400 A, worked out in Figure 13.14, when both the sections were fed from individual busbars.

5 Rated short-time current rating or fault level of a system

To establish the fault level of a system

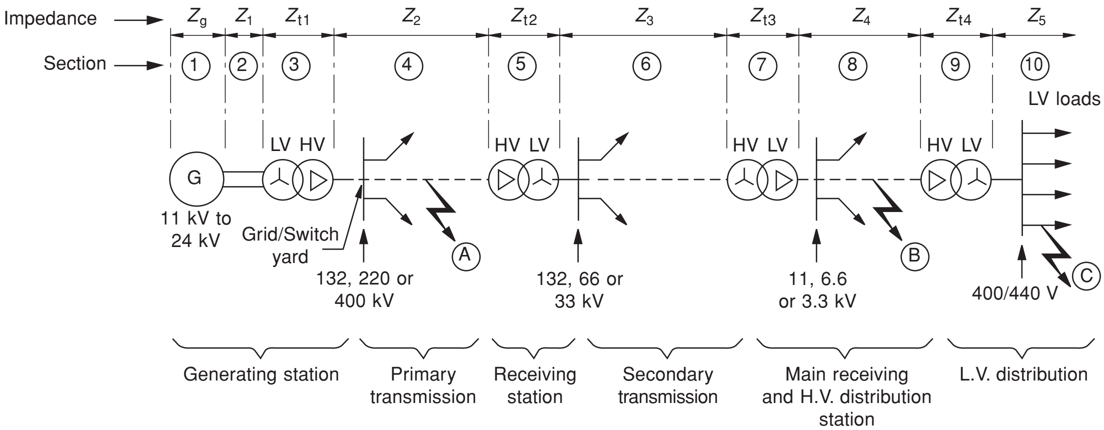
The fault level of an electrical network is the capacity of the source of supply to feed the faulty circuit, and is represented in kVA or MVA. Consider the simple transmission and distribution network of Figure 23.1, which is redrawn in Figure 13.15 for more clarity. This illustrates the impedances of the network at various points, and their role in the event of a fault. The impedance of a circuit is built through the self-impedances of the windings of the various machines in the circuit, generators, transformers and motors etc., and the impedances of the connecting transmission and distribution lines and the associated cables.

To increase the impedance of the network, a series resistor or reactor is sometimes used to contain the fault level of a system within a desirable limit. This may be required to make the selection of the interrupting device easy, and from the available range, without an extra cost for a new design as well as an economical selection of the inter-connecting conductors and cables. Such a situation may arise on HV >35 kV or EHV >230 kV transmission networks, when they are being fed by two or more power sources, which may raise the fault level of the system to an unacceptable level. Also refer to Example 13.5. The cost of the interrupting device for a very high fault level may become disproportionately high, and sometimes even pose a problem in availability.

Ground fault current is controlled by a method similar to that discussed in Section 20.4.2. The electricity authorities of a country generally provide the preferred fault levels, depending upon the availability of the interrupting devices. They also suggest the likely generation of over-voltages in a faulty circuit and the healthy phases on a ground fault as a result of grounding conditions, as guidelines to the system designers to design a transmission or a distribution network for various voltage systems. The guidelines may also recommend the maximum loading of a line and the maximum number of feeding lines that may be connected to a common grid, to limit the fault level of the system within the desirable limit. Some typical values are noted below:

Nominal system voltage	*Limiting fault level*	*No. of additional feeding lines*
765 kV	2500 MVA	Nil
400 kV	1000 MVA	5
220 kV	320 MVA	3
132 kV	150 MVA	2

For more details refer to Section 24.8. It is possible that with the passage of time more generating stations may be installed to meet the rising demand for power. Their feeding lines too will be added to the existing grid to augment its capacity. This would also enhance the fault level of the existing system. To ensure that the prescribed



(1) Generator.

(2) Isolated phase bus system

(3) EHV generator transformer

(4) EHV transmission line

(5) H.V. secondary transmission transformer

(6) Secondary transmission line

(7) H.V. distribution transformer

(8) H.V. distribution network

(9) L.V. distribution transformer

(10) L.V. distribution network

(i) Fault at 'A' is calculated by impedance Z_{t1}
(ii) Fault at 'B' is calculated by impedance Z_{t3}
(iii) Fault at 'C' is calculated by impedance Z_{t4}

Note The actual fault at any point will be much lower than calculated with the above impedances Z_{t1}, Z_{t2}, Z_{t3} and Z_{t4} because other impedances from the source of supply (Transformers in the above case) up to the point of fault, are not considered while designing a system.

Figure 13.15 Typical layout of a transmission and distribution network and significance of circuit impedances at various points

fault level is not exceeded, a detailed network analysis may be carried out to determine the minimum possible impedance of the grid, at various vulnerable locations, to establish the likely revised fault level. If it is felt that it may exceed the prescribed limit, current-limiting series reactors may be provided at suitable locations to yet contain the fault level within the prescribed limits. For current limiting reactors refer to Chapter 27.

With the availability of more advanced interrupters in future, it will be possible to upgrade the present guidelines and permit connections of more feeding lines on an existing grid without having to resort to a series reactor. Below, we analyze the likely fault levels of a system under different circuits and fault conditions for an easy understanding of the subject. It is a prerequisite to decide the level of fault, to select and design the right type of equipment, devices and components and the protective scheme for a particular network.

A power circuit is basically an R-L circuit. In the event of a fault, the system voltage ($V_m \sin \omega_t$) may occur somewhere between $V = 0$ and $V = V_m$ on its voltage wave. This will cause a shift in the zero axis of the fault current, I_{sc}, and give rise to a d.c. component. The fault current will generally assume an asymmetrical waveform as illustrated in Figure 13.27.

The magnitudes of symmetrical and non-symmetrical fault currents, under different conditions of fault and configurations of faulty circuits, can be determined from Table 13.5 once the values of Z_1, Z_2 and Z_0 are known.

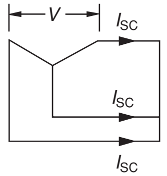
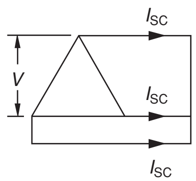
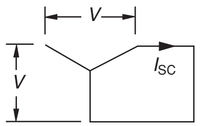
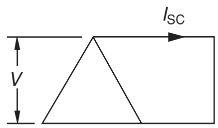
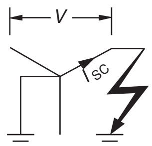
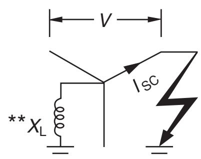
Z_1 = Positive phase sequence impedance, measured under symmetrical load conditions. The following values of Z_1 may be considered:

1(i) Cables: In case of cables Z_1 is equal to the phase impedance. For low current cables (LV and HV) this impedance may be considered as equal to the resistances of the cables as $R >> X_L$ (see cable tables Chapter 16, Appendix). Due to very low X_L at low currents, the impedance does not alter significantly even on a fault as bulk of the magnetic field occupies the space rather than causing self-inductance. The ideal transposition of cables almost nullifies the mutual inductances in the adjacent phases. For all practical purposes therefore, in small ratings the resistance of cables, R may be considered as its impedance even on a fault without much error.

At higher currents, R diminishes rather sharply ($R \propto 1/I^2$) than the inductance. As the magnetic field becomes stronger at higher currents the flux occupies more of space than causing self or mutual inductances. Yet X_L attains significant value gradually compared to R. The impedance of cables can now be considered as $Z = R + JX_L$. On faults also X_L now plays a significant role in containing the fault level of the circuit.

(ii) Bus systems: Now also Z_1 is equal to the impedance of the bus section per phase. But the bus configuration

Table 13.5 RMS values of fault currents under different conditions of fault in a power system

Sr. no.	*Type of fault*	*Configuration of faulty circuit*	*Fault currents*	
			Symmetrical	*Unsymmetrical*
1	3-Phase	(i) Star connected with isolated neutral 	$\frac{V}{\sqrt{3}} \times \frac{1}{Z_1}$	–
		(ii) Delta connected 	$\frac{V}{\sqrt{3}} \times \frac{1}{Z_1}$	–
2	Phase to phase	(i) Star connected with isolated neutral 	–	$\sqrt{3} \times \frac{V}{\sqrt{3}} \times \frac{1}{Z_1 + Z_2}$
		(ii) Delta connected 	–	$\sqrt{3} \times \frac{V}{\sqrt{3}} \times \frac{1}{Z_1 + Z_2}$
3	Phase or phases to ground	(i) Star connected, solidly grounded 	–	$\left(3^* \times \frac{V}{\sqrt{3}} \times \frac{1}{Z_1 + Z_2 + Z_0}\right)$
		(ii) Star connected, impedance grounded 	–	$\left(3^* \times \frac{V}{\sqrt{3}} \times \frac{1}{Z_1 + Z_2 + Z_0 + 3X_L^{**}}\right)$

Notes
* Refer to Section 20.4
** When the neutral is impedance grounded, three times its impedance must be added to Z_0, in view that this impedance would fall in series with each phase.

is different from that of cables as they are usually placed in a horizontal or vertical formation (except GIS and GIBs where they can be placed in a trefoil formation also (Section 19.10)), unlike cables that are in trefoil formation (except single phase cables). The busbars are therefore subject to high mutual induction and possess large X_L (see Table 30.7 and a few others) and $Z = R + JX_L$. Under fault condition

X_L plays a significant role now also as it rises further and contains the fault level of the system.

2 **Overhead lines:** Now also Z_1 is the impedance of the overhead line per phase, refer to Tables 24.1(a) and (b) and Section 24.6 for more details.

3 **Transformers and motors:** Now the situation is different from above. The Z_1 is equal to the short-circuit impedance of transformers and motors. Now the machine undergoes a quick change of flux, due to a change in the applied voltage (it changes two peaks in one half of a cycle, Section 1.2.1). The impedance during a fault is therefore different from that during normal running. As standard practice, the fault impedance is provided in p.u. by the machine manufacturers (see Table 13.8). The content of R is now far too low, compared to X_L ($R << X_L$), as is the p.f. of the faulty circuit.

4 **Reactors and capacitors:** The Z_1 is equal to the short-circuit impedance of the reactors or capacitors.

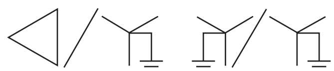
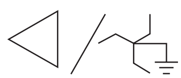
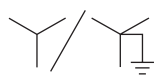
5 **Generators:** The Z_1 is equal to the sub-transient impedance (X''_d) of a generator as discussed later.

Z_2 = Negative phase sequence impedance
Z_0 = Zero phase sequence impedance

These impedances are provided by the manufacturers by actual measurement. For procedure of measurement see Section 20.4. When these data are not readily available, the approximations, as indicated in Table 13.6, may be assumed to complete the design work. The relay settings for the actual protection may be made later.

As discussed above, it is usual practice to assume the highest fault level of a network by considering the least possible impedance of the faulty circuit such as the impedance of the source of supply alone and selecting the equipment and devices for the worst-case operating conditions. The highest impedance is considered when setting the protective relays to make them actuate even on the smallest fault (other than of a transitory nature).

Table 13.6 Approximate negative and zero phase sequence impedances compared to positive phase sequence impedances

Component	Z_1	Z_2	Z_0	
Cables[a] (i) 3-Core cables (ii) 1-Core cables	Z_1	$Z_2 = Z_1$		$Z_0 = 3$ to $5\ Z_1$ $Z_0 = 1.25\ Z_1$
Overhead lines: (i) Single circuit	Z_1	$Z_2 = Z_1$	(i) Steel ground wire, (ii) Non-magnetic ground wire, (iii) No-ground wire,	$Z_0{}^* = 3.5 Z_1$ $Z_0{}^* = 2 Z_1$ $Z_0{}^* = 3.5 Z_1$
(ii) Double circuit	Z_1	$Z_2 = Z_1$	(i) Steel ground wire, (ii) Non-magnetic ground wire, (iii) No ground wire,	$Z_0{}^* = 5 Z_1$ $Z_0{}^* = 3 Z_1$ $Z_0{}^* = 5.5 Z_1$
Motors	Z_1	$Z_2 < Z_1$ [$\simeq$ 60–80% of Z_1]		$Z_0 = \infty$
Transformers	Z_1	$Z_2 = Z_1$	(i) 	$Z_0 = Z_1$
			(ii) 	$Z_0 = Z_1$
			(iii) 	$Z_0 = 0.66\ Z_1$
			(iv) For other configurations	$Z_0 = \infty$
Reactors Capacitors	$Z_1 = X_L{}^{**}$ $Z_1 = X_C{}^{**}$	$Z_2 = X_L{}^{**}$ $Z_2 = X_C{}^{**}$		$Z_0 = X_L{}^{**}$ $Z_0 = X_C{}^{**}$
Generators	$Z_1 = X''_d$	$Z_2 < Z_1$ [$\simeq$ 60–80% of Z_1]	(Also refer to Section 16.13.2.)	$Z_0 << Z_1$ or Z_2 [$\simeq$ 25–40% of Z_1]

[a]Similar values may be considered for a bus system also.
* These values will vary with the spacings between the conductors and their current ratings.
** In both cases, the content of loss is low. The resistance r, being very small, is neglected.

Note
The impedances marked on Figure 13.15 refer to positive phase sequence impedances only. Faults that are non-symmetrical alone would use negative or zero sequence impedances.

Inferences from Table 13.6

Rotating machines
These have $Z_2 < Z_1$ and

$$Z_0 << Z_1 \text{ or } Z_2$$

Therefore, the level of phase-to-phase asymmetrical faults will be generally of the same order as the three-phase symmetrical faults. The ground faults, however, will be higher than the symmetrical faults. Special care therefore needs be taken while grounding a generator, when they are solidly grounded, particularly to limit the ground fault currents. See also Section 16.13.2.

Other than rotating machines
For all stationary equipment such as transmission lines, transformers, reactors and cables.

$Z_2 = Z_1$ and $Z_0 \geq Z_1$

Therefore the level of three-phase symmetrical faults will be the highest compared to a phase-to-phase or a ground fault and the system design may be based on the symmetrical fault level.

A transformer is not a source of supply (it only transforms one voltage to another) but it is considered so, in terms of fault level calculations. In fact, it provides a means to add to the impedance of a circuit on the lower voltage side, and limits the fault level of the network to which it is connected. One will appreciate that the capacity of the actual source of supply, on the higher voltage side, will be much larger. On the LV side it is controlled by the impedance of the transformer. It is customary to consider this impedance to determine the fault level on the LV side. The fault level is measured as the dead short-circuit at the transformer LV side terminals, and this level is then assigned as the fault level for the connected bus system and the switchgear assemblies.

The philosophy to assume the impedance of the source of supply (generator or a transformer) as the impedance of the faulty circuit is too theoretical and may give a very high fault current. In actual operation, the fault intensity may be far less, as every device and component connected in the circuit will tend to add to the effective impedance of the faulty circuit and limit the magnitude of the fault current. Figure 13.15 also subscribes to this theory. But it is customary to design the systems for the worst fault conditions which, in all likelihood, may not arise, while decide the protective scheme and the current settings of the protective relays for the minimum possible fault current to be on the safe side.

To establish the minimum fault level, impedances of the feeding lines from the source of supply up to a selected point, at which the fault level is to be determined, must be added. For a step-by-step calculation to arrive at such a fault level refer to IEC 60909 and the literature on the subject as well as the references at the end of this chapter.

Example 13.2
Consider a 1500 kVA, 11 kV/415 V transformer designed especially to have a unit impedance of 7.5%:

$$\therefore \quad I_r = \frac{1500 \times 1000}{\sqrt{3} \times 415} \text{ A}$$

$$\simeq 2087 \text{ A}$$

$$\therefore \; I_{SC} = \frac{2087}{0.075} \text{ A} \qquad \text{(refer to Equation (13.5))}$$

$$\simeq 27.83 \text{ kA}$$

The prescribed system standard fault level nearest to it, as per Table 13.7 = 35 kA

$$\text{and in MVA} = \sqrt{3} \times 415 \times 35 \times 10^{-3} \text{ MVA}$$

$$\simeq 25 \text{ MVA}$$

This is a simple calculation to determine the maximum symmetrical fault level of a system, to select the type of equipment, devices and bus system etc. But to decide on a realistic protective scheme, the asymmetrical value of the fault current must be estimated by including all the likely impedances of the circuit.

Fault levels of an LV system

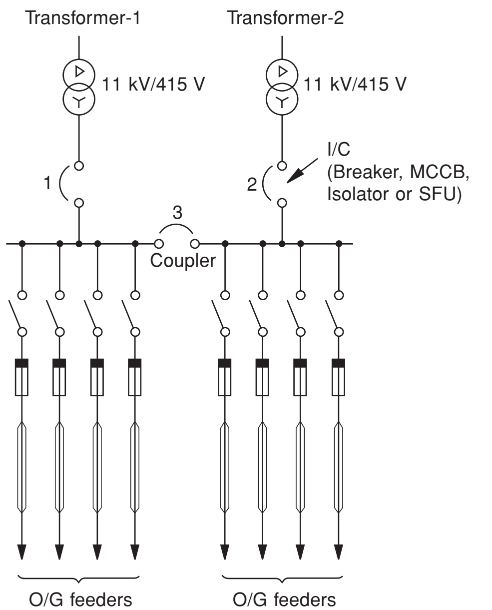
Table 13.7 suggests some standard ratings of the distribution transformers, their full load current on the LV side and the corresponding fault level, considering an average impedance according to IEC 60076-1. Referring to transformers of 2500 kVA and 3000 kVA, the fault current, assuming an impedance of 6.25% for 2500 kVA and 7% for 3000 kVA, will work out to more than 50 kA. The LV protective systems, as normally designed and manufactured, are suitable for a fault level up to 50 kA or so (see Table 13.7 and the note). It is, therefore, recommended that the size of the transformers for the LV distribution may be chosen, as far as possible, up to 2000 kVA. For large industrial and other LV loads, the practice is to choose more than one transformer of smaller ratings, to cater for the required load, rather than one transformer of larger capacity. In the same context, when more than one transformer are used to feed a large industrial load, distribution of the load must also be done in as many sections as the number of transformers. The parallel running of any two of the transformers must be avoided, even when they are suitable for a parallel operation and the source of supply is also the same. Otherwise the impedances of all the transformers that may be running in parallel would also fall in parallel. It will reduce the effective impedance of the faulty circuit, and multiply the system fault level. Use of current limiting reactors on LV systems is not a recommended practice, for reasons of relatively much higher losses of the reactor, compared to the power handled by it. A few typical, but generally adopted, distribution networks are illustrated in Figures 13.16 and 13.17.

Another factor that may discourage the use of higher ratings of transformers is the need to run a number of cables in parallel, to cater for such high currents. It may prove to be cumbersome, besides requiring a very high derating of the cables. Even the design of such large ratings of bus systems and their high eddy and magnetizing space currents would call for highly skilled engineering.

Table 13.7 For an LV system: typical fault levels on the LV side of a transformer

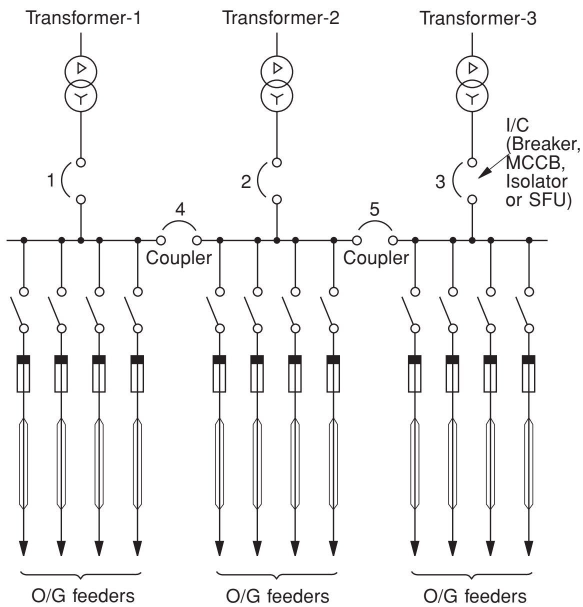
Transformer rating	*I_r at 415 V*	*I_r at 400V*	*Likely short-circuit unit impedance of a transformer as in IEC 60076-1*	*Fault current $I_{sc}(I_r/unit\ z_p)$ at 415V*	*Fault current $I_{sc}(I_r/unit\ z_p)$ at 400V*	*Fault level $[\sqrt{3}\cdot V_r\cdot I_{sc}]$ at 415 or 400V*	*Standard 1-second systems in practice*			
MVA	*Amps. (r.m.s.)*	*Amps. (r.m.s.)*	*z_p %*	*kA (r.m.s.)*	*kA (r.m.s.)*	*MVA*	*kA (r.m.s.)*	*MVA at 415 V*	*MVA at 400V*	
0.5	696	722	4.5	15.47	16.04	11.0	25	18	17	Preferred ratings
0.75	1043	1082	5.0	20.86	21.64	15.0				
1.00	1391	1443	5.0	27.82	28.86	20.0				
1.25	1739	1804	5.0	34.78	36.08	25.0	35	25	24	
1.50	2087	2165	6.25	33.39	34.64	24.0				
2.00	2783	2887	6.25	44.53	46.19	32.0	43	31	30	
*2.50	3478	3609	6.25	55.65	57.75	40.0	50	36	35	Non-preferred rating

**Note*
With the availability of modern circuit breakers with higher short-time ratings of 65/80 and 100 kA and thermal ratings up to 6300 A, it is now possible to use even larger transformers up to 3000 kVA, depending upon their other merits. For quick estimate of fault current consider z_p as 7% for this rating.



Caution
The configuration represents scheme of two incomings and one bus coupler. To avoid parallel operation, only two of these must be 'ON' at a time.

Figure 13.16 Interlocking requirements



Caution
The configuration represents scheme of three incomings and two bus couplers. To avoid parallel operation, only three of these five must be 'ON' at a time. To achieve this provide 5 locks and 3 keys such that

– key 1 can open lock 1 or 4 and no other lock
– key 2 can open lock 2 or 4 or 5 and no other lock
– key 3 can open lock 3 or 5 and no other lock

Also see Section 13.7.5 and Figure 13.41

Figure 13.17 Interlocking requirements

A single large transformer will also provide less flexibility to the system. A fault in this transformer or its shutdown for a normal maintenance will result in the shutdown of the whole installation. However, a single large transformer has its own merits also. The user may evaluate which system would suit him the best and decide the rating accordingly.

With the availability of high rating (up to 6300 A) and high interrupting capacity (up to 100 kA) LV circuit breakers (Section 19.5.3) and low loss compact bus systems (Section 28.2.6) it is now possible to employ higher rating transformers. Higher I_{sc} may however, demand for higher cross-sections of main current carrying components, busbars and connecting links commensurate to $I_{sc}^2 \cdot t$ (t being interrupting time of protective device being used). In all likelihood it is possible that lower fault clearing time may compensate for the increase in fault level. Referring to Table 13.7 if we use one 2.5 MVA, 400 V transformer the heating with 0.5 s tripping will be $\propto (57.75 / 50)^2 \times 0.5$ or 0.67 times the heating with a 50 kA, 1s system. Nevertheless since the I_{sc} shall be able to reach the first peak (the protective device being fast acting not current limiting), the mechanical strength of busbars, their mounts and supports will require to be supported rigidly to sustain higher EM forces (F_m) as a consequence of higher I_{sc} and reinforced for $F_m \propto (57.75 / 50)^2$ or 33% more than for 50 kA, 1s system.

Corollary – The usual practice of large consumers is to have their own captive generation. To economize cost on MV/HV system they may sometimes choose for large LV turbo-alternators or diesel generators as large as 3–4 MVA. It surely calls for a careful consideration before a final decision in light of high fault level of the system. Though the modern LV air circuit breakers may be capable of interrupting large fault currents (up to 100 kA), they are not current limiting. The point under consideration is the consequent electromagnetic forces 'Fm' that may be enormous and catastrophic as they may attain their maximum values and for which must be suitable the entire busbar system. It is irrespective of the fact that the protective device may be fast acting and isolating the faulty circuit within 0.1–0.15 s.

Fault level of a system under cumulative influence of two power sources

Short-time rating of the tap-offs

It is possible that in certain installations as a result of system needs it may not be possible to limit the fault level of the system within a desirable limit. A power-generating station, connected to an external grid, to augment the capacity of the power network is one example. Figure 13.21 (described later) illustrates a typical electrical layout of a power-generating station where the generator G is connected to an external grid. The generator voltage is normally much lower than the voltage of the external grid. It is therefore connected to the grid through a step-up generator transformer GT. The fault level of the grid on the generator side is thus governed by the impedance of the GT. In the event of a fault on this section, say at the bus section connecting G with GT, one side of it will be fed by the G and the other by the GT. Thus, no part of this section would carry a fault current of more than one source at a time. The main inter-connecting bus system between G and GT may therefore be designed for a fault level, whichever is the higher of the two sources.

Through the tap-offs of the bus, the unit auxiliary transformers (UATs) are connected to feed the station auxiliary services. For more clarity we have taken out the portion of the tap-offs from Figure 13.21 and redrawn it in Figure 13.18 to illustrate the above system and its inter-connections. The tap-offs are now subject to the cumulative influence of the two supply sources. In the event of a fault on this section, both the sources would feed the same and the fault current through the tap-offs would add up. The tap-offs should thus be designed for the cumulative effect of both fault levels. For the sake of an easy reference, Table 13.8 suggests a few typical values of fault currents, worked out on the basis of data considered for the G and GT. One such example is also worked out in Example 13.3.

Impulse level of the tap-offs

These sections should also possess a higher level of insulation, as prescribed in Table 32.1(a).

Example 13.3

Consider a generator G of 250 MW, 16.5 kV having a fault level of 61 kA and the generator transformer GT of 315 MVA, 16.5 kV/400 kV having a unit impedance of 14.5 ± 10% (Table 13.8, Figure 13.18)

∴ full load current of GT,

$$I_r = \frac{315}{\sqrt{3} \times 16.5} \text{ kA}$$

and fault current from Equation (13.5)

$$I_{sc} = \frac{315}{\sqrt{3} \times 16.5} \times \frac{1}{0.145 \times 0.9}$$

where z_p is considered with the lower tolerance, i.e. 14.5%–10%, to obtain the maximum level of fault current to design the system.

$\therefore I_{sc} \simeq 84$ kA

But the GT is connected to a power grid and the grid to a transmission system. If we consider the fault level of the transmission system as 40 kA, as in Table 13.10, then the maximum fault that can occur on the LV side of the GT will be governed by the fault level of the transmission system (40 kA) and not the GT (84 kA). It is another matter that being high current system, thermal consideration will override the short circuit requirement.

Accordingly, the fault level for which the tap-offs should be designed,

= 61 + 40

= 101 kA

and momentary current

= 101 × 2.5 (Table 13.11)

= 252.5 kA

One-minute power frequency withstand voltage from Table 32.1(a).

(i) For main inter-connecting bus between G and GT – 50 kV
(ii) For the tap-offs – 55 kV

Note
For guidance on short-circuit calculations refer to IEC 60909.

Table 13.8 Typical parameters of a power generating station and its likely fault levels

1 Generator								
Generator size (rated MVA × p.f.)	MW	60	67.5	110	120	200/210	250	500
Approximate sub-transient unit reactance,	x''_d(%)	15.4	17.7	15.9	13.2	16.8	16.9	17.2
Rating	MVA	75	84.4	137.5	141.2	247	294	588
Generator fault level, $I_{SC} = \left(\frac{I_r}{\text{p.u.}\, x''_d}\right)$	kA	25.56	26.21	45.39	58.94	53.87	60.89	94.17
$[\sqrt{3} \times V_r \times I_{SC}]$	MVA	487	477	865	1072	1470	1740	3425
Rated p.f.		0.8	0.8	0.8	0.85	0.85	0.85	0.85
Stator nominal voltage, V_r	kV	11	10.5	11	10.5	15.75	16.5	21
Stator current (CMR)[a], I_r	A	3936	4639	7217	7780	9050	10 290	16 200
Frequency, f	Hz	50	50	50	50	50	50	50
2 Generator transformer (GT)								
Rating	MVA	75	85	140	140	250	315	600
Unit impedance	z_p%	12.5 ± 10%	12.5 ± 10%	12.5 ± 10%	12.5 ± 10%	14 ± 10%	14.5 ± 10%	15 ± 10%
Generator side fault level, considering the lower tolerance of impedance,	kA[b]	35	42	65	68	73	84	122
Vector group		← Star/delta (YNd 11) →						
Type		← Three-phase, two winding →						One-phase two-winding, 3 Nos 200 MVA each
3 Generator isolated phase bus (IPB) duct								
Rated current (CMR)[a]	A	4000	5000	8000	8000	10 000	12 500	18 000
One second short-time rating (as for GT)[b] (not to be more than the fault level of the grid)	kA	35	42	65	68	73	84	122
4 Tap-offs of the generator bus duct								
Approximate one-second short-time rating (rounded off)[b] (it is the summation of the fault levels of the generator and the generator bus duct: refer to Figure 13.18 and a typical calculation in Example 13.3)	kA	61	68	110	127	127	145	216
5 Unit auxiliary transformer (UAT)								
No. of transformers		1	1	1	1	1 or 2	1 or 2	2
Rating	MVA	8	8	12.5	16	25 for 1 and 12.5 for 2	31.5 for 1 and 16 for 2	2 of 25 or 2 of 31.5
Impedance	Z_p%	7	7	7.5	7.5	10 for 25 MVA 7.5 for 12.5 MVA	10 for 31.5 MVA 7.5 for 16 MVA	10 for 25 MVA 10 for 31.5 MVA
Vector group type		← Dyn1 or Ddo → ← 3-phase, 2 winding →						

Source: NTPC and BHEL.

[a]CMR – Continuous maximum rating

[b]The GT HV side is connected to a power grid and the grid receives power from many sources and can have a fault level higher than that of G or the GT. On a fault anywhere in the main length or the tap-offs of the IPB between G and the GT (Figures 13.21 and 13.18 respectively) both generator and the grid will feed the fault (grid through the GT). The fault level of the IPB straight length may therefore be considered as the fault level of the generator or the grid whichever is more. Grid fault level being limited up to the fault level of the GT (impedance of GT limiting the fault level). Accordingly we have considered the fault level of the straight length of the IPB as the fault level of the GT assuming that the fault level of the grid is more than the fault level of G or GT. It is, however, only for illustration, exact fault level shall depend upon the system parameters, also refer to Example 13.3 for more clarity.

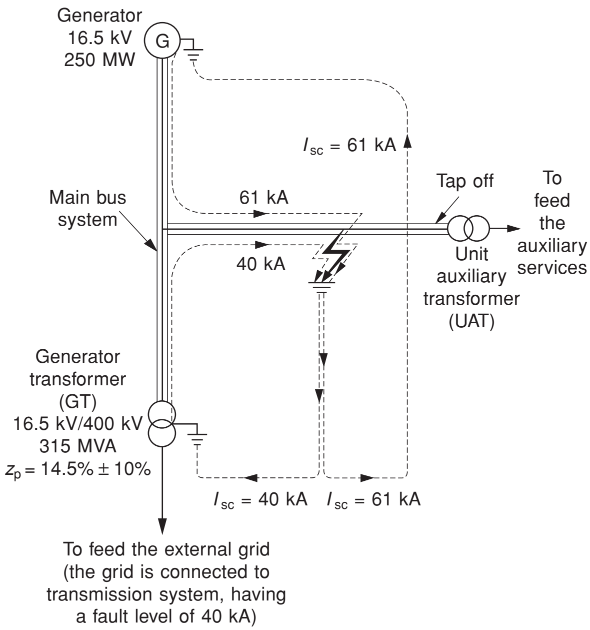
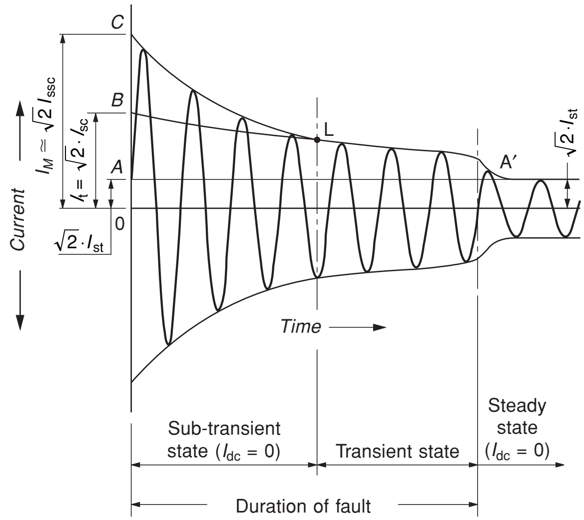


Figure 13.18 Fault level of tap-offs of a bus system under cumulative influence of two power sources



Symmetrical fault current at V_{max}, when I_{dc} = 0

Figure 13.19 Short-circuit oscillogram of a generator

Fault level of a generator circuit

The condition of a fault on a generator is similar to a fault in an R–L series circuit, as noted in Table 13.5, except for the effect of armature reaction and variation in the field current. The current waveform of a generator under a fault condition, therefore, becomes modified as a result of armature reaction. Since the flux crossing the air gap during a short-circuit in the first few cycles is large, the reactance is the least because of saturation effect (Figure 27.2) and short-circuit current the highest. This current is termed the sub-transient symmetrical fault current (I_{ssc}). The impedance at the instant of the short-circuit that determines this current is termed the sub-transient reactance X''_d. The *r* being too little is normally ignored. I_{ssc} exists in the system for just three or four cycles, depending upon its rate of decay, which is a function of I_{ssc}/I_r. The design parameters of the generator must ensure that its peak value including the d.c. component does not exceed 15 times the peak rated current of the machine ($15 \times \sqrt{2} \cdot I_r$ or $21 \cdot I_r$ as in IEC 60034-1). It corresponds to the current of the first peak.

These reactances are measured by creating a fault, similar to the method discussed in Section 14.3.6. The only difference now is that the fault is created in any of the phases at an instant, when the applied voltage in that phase is at its peak, i.e. at V_m, so that the d.c. component of the short-circuit current is zero and the waveform is symmetrical about its axis, as shown in Figure 13.19, where,

(i) *CL* – defines the sub-transient state and

$$I_{ssc(r.m.s.)} = \frac{OC}{\sqrt{2}} = \frac{1}{\sqrt{2}} \times \frac{V_m}{\sqrt{3} \cdot X''_d} = \frac{V_l}{\sqrt{3} \cdot X''_d}$$

and the magnitude of the first peak can be defined by

$$I_M = \sqrt{2} \cdot I_{ssc(r.m.s.)}$$

$I_{ssc\,(r.m.s.)}$ = sub-transient state symmetrical short-circuit current, occurring for only three or four cycles.
It is the initial symmetrical short-circuit current, and serves as the basis of calculation for the peak asymmetrical short-circuit current or the making current, I_M, of an interrupting device.

(ii) *BL* – defines the transient state and

$$I_{sc(r.m.s.)} = \frac{OB}{\sqrt{2}} = \frac{1}{\sqrt{2}} \cdot \frac{V_m}{\sqrt{3} \cdot X'_d} = \frac{V_l}{\sqrt{3} \cdot X'_d}$$

$I_{sc\,(r.m.s.)}$ = transient state short-circuit current or symmetrical fault current of the system. It is used to determine the breaking current on fault of an interrupting device. I_{sc} also determines its heating effect on the circuit current carrying components, wiring, inter-linking, terminals and busbars.

I_t = Transient state peak symmetrical short-circuit current. = $\sqrt{2} \cdot I_{sc}$

(iii) *AA′* – defines the steady-state condition and

$$I_{sc(r.m.s.)} = \frac{OA}{\sqrt{2}} = \frac{1}{\sqrt{2}} \cdot \frac{V_m}{\sqrt{3} \cdot X_d} = \frac{V_l}{\sqrt{3} \cdot X_d}$$

$I_{st\,(r.m.s.)}$ = steady-state continuous short-circuit current after the transient state. It may be slightly higher than the rated current (I_r) of the machine, due to small d.c. components, which may still be present in the system.

X''_d = sub-transient state symmetrical reactance – Ω/phase
The maximum value of this reactance will depend upon the voltage regulation grade and is specified in BS 4999–140, for different grades.

X'_d = transient state symmetrical reactance – Ω/phase.
Since the interrupter will take at least three or four cycles to operate from the instant of fault initiation, it is this transient reactance that is more relevant for the purpose of short-circuit calculations.

X_d = steady-state symmetrical (synchronous) reactance – Ω/phase.

r = series resistance of the generator, being too small, 0.5–10% of the sub-transient reactance, i.e. $r << X''_d$, is normally ignored for ease of calculation.

V_1 = Generator line voltage-volts

Summary

I_M – is a measure of structural suitability on which are mounted the current carrying components to withstand the electro-dynamic forces arising during a short circuit. It also defines the making capacity 'on fault' of an interruping device. The first peak of I_{ssc} alone is therefore relevant. For ease of application it is represented in terms of I_{sc}. Table 13.11 suggests the multiplying factors on I_{sc} to determine I_M.

I_{sc} – is a measure of heating efffect on current carrying components and also the breaking capacity of an interrupting device on fault. The heating is measured after a lapse of 1 or 3s depending on the system requirement, while the breaking capacity is determined within first few cycles.

Per unit (p.u.) values

In normal practice the above parameters are provided on a per unit (p.u.) basis only where

$$X_b = \frac{V_1}{\sqrt{3} \cdot I_r} \ \Omega/\text{phase}$$

X_b – may be any chosen base reactance

$$\text{and } x(\text{p.u.}) = \frac{X}{X_b}$$

$$= 3 \cdot \frac{X \cdot (\text{base kVA}) \cdot 1000}{(\text{base } V_1^2)} \times 100\% \text{ etc.}$$

(see Equation (13.3))

The magnitudes of fault currents under different conditions of fault are analyzed in Table 13.9. Figure 14.5 has been redrawn in Figure 13.20 for a generator circuit illustrating the sub-transient, transient and steady state currents on an actual fault. The curve depicts the most severe fault condition which occurs when the circuit voltage is the minimum, i.e. at V_0, causing the maximum asymmetry and the associated d.c. component.

Example 13.4

The generator of a 1000 kVA, 415 V, 3-ϕ DG set has the following reactances:

X_d = 0.172 Ω/phase
X'_d = 0.028 Ω/phase
X''_d = 0.02 Ω/phase
X_2 = 0.015 Ω/phase
X_0 = 0.007 Ω/phase

$$I_r = \frac{1000 \times 1000}{\sqrt{3} \times 415}$$

$$= 1391 \text{ A}$$

and base reactance

$$X_b = \frac{415}{\sqrt{3} \times 1391}$$

$$= 0.172 \ \Omega/\text{phase}$$

∴ the corresponding unit reactances for the above per phase reactances will be $\left\{x = \frac{X_d}{X_b}\right\}$

x_d = 0.988 or 98.8%
x'_d = 0.162 or 16.2%
x''_d = 0.116 or 11.6%
x_2 = 0.087 or 8.7%
x_0 = 0.041 or 4.1%

and the symmetrical fault currents using basic parameters will be

(i) Sub-transient current

$$I_{\text{SSC r.m.s.}} = \frac{415}{\sqrt{3} \times 0.02}$$

$$= 11.98 \text{ kA}$$

and the magnitude of the first peak, including the d.c. component;

$$I_M = \sqrt{2} \times 11.98$$

$$= 16.94 \text{ kA}$$

(ii) Transient current

$$I_{\text{sc r.m.s.}} = \frac{415}{\sqrt{3} \times 0.028}$$

$$= 8.56 \text{ kA}$$

and peak short-time current, $I_t = \sqrt{2} \times 8.56$

$= 12.10$ kA

(iii) The factor of asymmetry

$$= \frac{\text{Magnitude of the first peak current } (I_M)}{\text{Symmetrical transient rms current } (I_{sc})}$$

$$= \frac{16.94}{8.56}$$

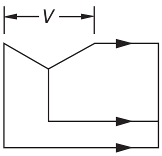
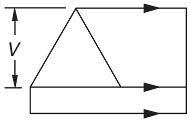
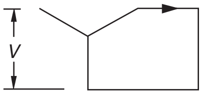
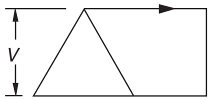
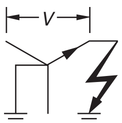
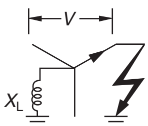
= 1.98, which is nearly the same as given in Table 13.11

(iv) Steady-state short-circuit current

$$I_{\text{st r.m.s.}} = \frac{415}{\sqrt{3} \times 0.172}$$

$$= 1.39 \text{ kA}$$

Table 13.9 Fault currents (r.m.s.) in a generator circuit under different fault conditions

Sr. no.	*Type of fault and configuration of faulty circuit*	*Fault currents*		
		Sub-transient $I_{SSC(r.m.s.)} = \frac{I_M}{\sqrt{2}}$	*Transient* $I_{sc(r.m.s.)} = \frac{I_t}{\sqrt{2}}$	*Steady state* $I_{st(r.m.s.)} \simeq I_r$
1	Three-phase fault			
	(i) Star connected 	$\frac{V_1}{\sqrt{3}} \cdot \frac{1}{X''_d}$	$\frac{V_1}{\sqrt{3}} \cdot \frac{1}{X'_d}$	$\frac{V_1}{\sqrt{3}} \cdot \frac{1}{X_d}$
	(ii) Delta connected 	$\frac{V_1}{\sqrt{3}} \cdot \frac{1}{X''_d}$	$\frac{V_1}{\sqrt{3}} \cdot \frac{1}{X'_d}$	$\frac{V_1}{\sqrt{3}} \cdot \frac{1}{X_d}$
2	Phase to phase fault			
	(i) Star connected 	$\sqrt{3} \cdot \frac{V_1}{\sqrt{3}} \cdot \frac{1}{X''_d + X_2}$	$\sqrt{3} \cdot \frac{V_1}{\sqrt{3}} \cdot \frac{1}{X'_d + X_2}$	$\sqrt{3} \cdot \frac{V_1}{\sqrt{3}} \cdot \frac{1}{X_d + X_2}$
	(ii) Delta connected 	$\sqrt{3} \cdot \frac{V_1}{\sqrt{3}} \cdot \frac{1}{X''_d + X_2}$	$\sqrt{3} \cdot \frac{V_1}{\sqrt{3}} \cdot \frac{1}{X'_d + X_2}$	$\sqrt{3} \cdot \frac{V_1}{\sqrt{3}} \cdot \frac{1}{X_d + X_2}$
3	Phase or phases to ground fault			
	(i) Solidly grounded 	$3 \cdot \frac{V_1}{\sqrt{3}} \cdot \frac{1}{X''_d + X_2 + X_0}$	$3 \cdot \frac{V_1}{\sqrt{3}} \cdot \frac{1}{X'_d + X_2 + X_0}$	$3 \cdot \frac{V_1}{\sqrt{3}} \cdot \frac{1}{X_d + X_2 + X_0}$
	(ii) Impedance grounded 	$3 \cdot \frac{V_1}{\sqrt{3}} \times \frac{1}{(X''_d + X_2 + X_0 + 3X_L)}$	$3 \cdot \frac{V_1}{\sqrt{3}} \times \frac{1}{(X'_d + X_2 + X_0 + 3X_L)}$	$3 \cdot \frac{V_1}{\sqrt{3}} \times \frac{1}{(X_d + X_2 + X_0 + 3X_L)}$

Notes

1 The above are r.m.s. values. For peak values multiply them by $\sqrt{2}$.
2 The first peak with full asymmetry, i.e. the making current I_M, will be represented by $\geq (P \times I_{sc})$ (where P = factor of asymmetry as in Table 13.11).
3 X_2 and X_0 are negative and zero phase sequence reactances of the generator respectively, in Ω/phase.
4 Since the ground fault currents in generators can be higher (Section 16.13.2) than the sub-transient state current, special care need be taken while grounding a generator to limit the ground fault current. Section 16.13.2 covers this aspect also.
5 The relays and the breaker will operate only during the transient state, hence the significance of transient state values to set the current and the time of the protective and isolating devices.
6 In certain cases, where a long delay may be necessary for the protective scheme to operate, it may be desirable to use the maximum steady-state short-circuit current $\sqrt{2} \cdot I_{st}$ for a more appropriate setting, rather than the maximum transient current $\sqrt{2} \cdot I_{sc}$, as by then the fault current will also fall to a near steady-state value, $I_{st(r.m.s.)}$.

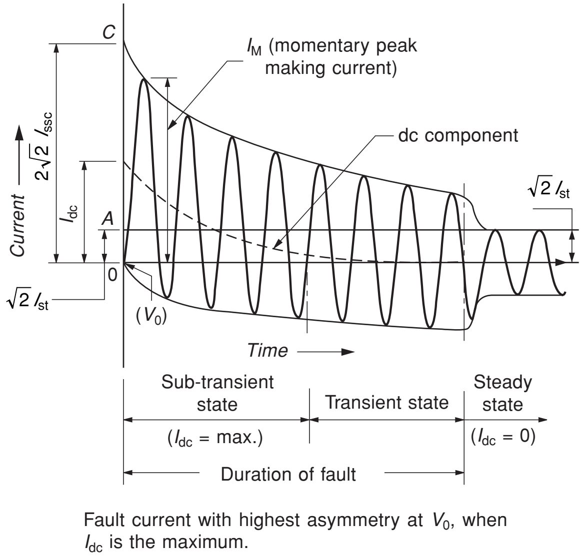


Figure 13.20 Short-circuit oscillogram of a generator

which is equal to the full load current (I_r). The small difference, if any may be due to d.c. component

Note
Similar values are obtained using p.u. values like

$$I_{ssc(r.m.s.)} = \frac{I_r}{x''_d}$$

$$= \frac{1391}{0.116} = 11.99 \text{ kA}$$

The small difference is because of approximations.

Selection of bases

A power system is connected to a number of power supply machines that determine the fault level of that system (e.g. generators and transformers). The impedances of all such equipment and the impedances of the inter-connecting cables and overhead lines etc. are the parameters that limit the fault level of the system. For ease of calculation, when determining the fault level of such a system it is essential to consider any one major component as the base and convert the relevant parameters of the other equipment to that base, for a quicker calculation, to establish the required fault level. Below we provide a few common formulae for the calculation of faults on a p.u. basis. For more details refer to a textbook mentioned in the Further Reading.

$$\text{p.u.} = \frac{\text{Actual quantity}}{\text{Chosen base}} \qquad (13.1)$$

p.u. = per unit quantity of V, I or Z_1 (fault impedance) (e.g. for a base impedance of 10 Ω, 5 Ω will be 5/10, i.e. 0.5 p.u. or 50%)

$$kVA = \frac{\sqrt{3}\cdot V\cdot I}{1000} (V \text{ is in volts})$$

$$I = \frac{kVA}{\sqrt{3}\,V} \times 1000 \text{ A}$$

and $Z_1 = \frac{V}{\sqrt{3}}\cdot\frac{1}{I}$

$$= \frac{V^2}{kVA \times 1000}\,\Omega \qquad (13.2)$$

If z_p is the p.u. impedance then

$$z_p = \frac{\text{Actual impedance } (Z_1)}{\text{Chosen base impedance } (Z_b)}$$

where

$$Z_b = \frac{\text{Base } V^2}{\text{Base } kVA \times 1000}$$

$$\therefore\ z_p = \frac{Z_1\cdot(\text{base } kVA)\times 1000}{\text{Base } V^2} \text{ etc.} \qquad (13.3)$$

If z_{p1} = p.u. impedance at the original base, and
z_{p2} = p.u. impedance at the new base,

then

$$z_{p2} = z_{p1}\left(\frac{V_1^2}{kVA_1}\times\frac{kVA_2}{V_2^2}\right) \qquad (13.4)$$

where suffixes 1 and 2 refer to the original and the new base values respectively.

3-phase fault current $I_{sc} = \frac{V}{\sqrt{3}}\cdot\frac{1}{Z_1}$

from Equation 13.3 $Z_1 = \frac{V^2\cdot z_p}{kVA\cdot 1000}$

$$\therefore\quad I_{sc} = \frac{V}{\sqrt{3}}\cdot\frac{kVA\cdot 1000}{V^2\cdot z_p}$$

$$= \frac{\text{kVA}\cdot 1000}{\sqrt{3}\cdot \text{V}\cdot z_p}$$

Since $I_r = \frac{kVA\cdot 1000}{\sqrt{3}\cdot V}$

∴ Fault current I_{sc}

$$= \frac{I_r}{z_p} \text{ i.e. } \frac{\text{Rated current}}{\text{Transient unit impedance}} \qquad (13.5)$$

and fault MVA $= \frac{\text{Base MVA}}{z_p}$ etc. (13.6)

Example 13.5
Consider a switchyard receiving power from three of 200 MVA, 15.75 kV generating sources, having a unit impedance of 16 ± 10% each and feeding the transmission lines through 15.75/132 kV, 250 MVA generator transformers as shown in Figure 13.20(a) with a unit impedance of 14 ± 10% each (Table 13.8).

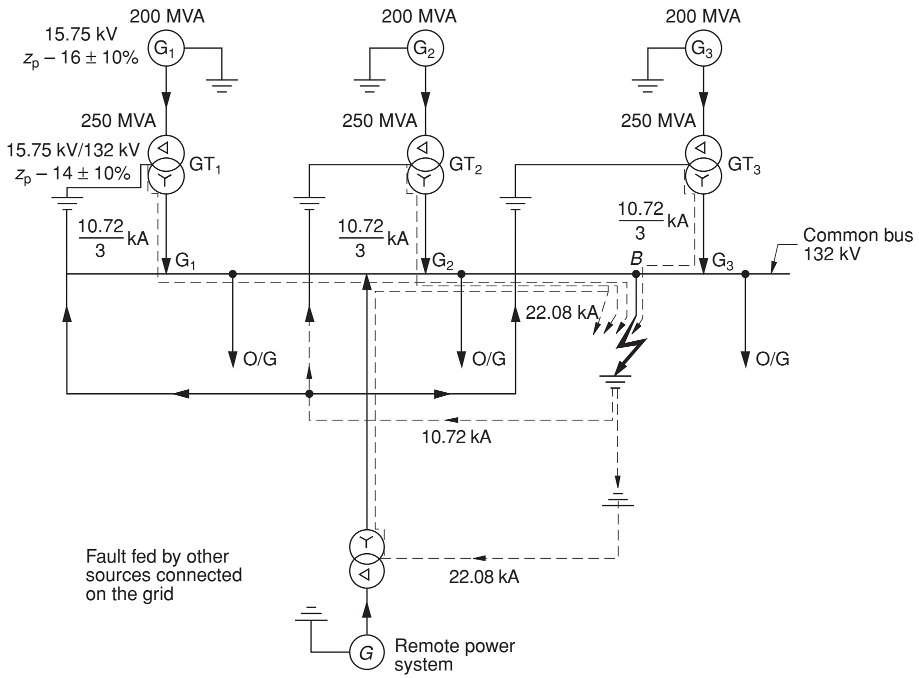


Figure 13.20(a) Illustration of Example 13.5

Considering the system fault level at 32.8 kA, calculate the fault contribution by the generating units;

In this case the sources feeding the fault are generators and not generator transformers (GTs). The GTs are only current limiters and introduce their reactances into the circuit. Since the ratings of the generators and the GTs are different, it is mandatory to first convert them to a common base, say, 200 MVA in this case. Therefore the combined unit impedance of each generator and the GT at point B, considering the lower value of the impedances to be on the safe side,

$$= (16 - 1.6) + (14 - 1.4)\,\frac{200}{250}$$

$$= 14.4 + 10.08$$

$$= 24.48\%$$

Since all three generators are operating in parallel, the impedance of each circuit, as calculated above, will fall in parallel and the equivalent impedance will become

$$\frac{1}{z_{eq}} = \frac{1}{24.48} + \frac{1}{24.48} + \frac{1}{24.48}$$

or $z_{eq} = \dfrac{24.48}{3}$

or 8.16% (0.0816 p.u.)

Full load current at base MVA

$$I_{\ell(\text{base})} = \frac{200}{\sqrt{3} \times 132}$$

$$= 0.875 \text{ kA}$$

$$\therefore \quad I_{sc} = \frac{0.875}{0.0816}$$

$$= 10.72 \text{ kA}$$

Since the system fault level is 32.8 kA, the fault contribution by the other sources connected on the grid

$$= 32.8 - 10.72$$

or 22.08 kA

Fault levels of HV systems

We illustrate a typical powerhouse generation and transmission system layout in Figure 13.21, and reproduce in Table 13.10 the typical fault levels of different transmission and distribution networks in practice for different voltage systems.

Table 13.10 Typical fault levels for an integrated transmission and distribution network

Nominal system voltage (Vr) kV (r.m.s.)	*Highest system voltage (V_m)* kV (r.m.s.)	*Symmetrical interrupting current rating* (r.m.s.) kA I_{sc}	*Momentary current peak for dynamic rating kA (peak)*
765	800	40	100
400	420	40	100
220	245	31.5/40	79/100
132	145	25/31	62.5/77.5
33	36	25	62.5
15/24kV*	–	–*–	–*–
11	12	40	100
6.6	7.2	40	100
3.3	3.6	40	100
0.415	0.44	43/50	90.0/105

*Since this represents the generator voltage, therefore the fault level will be governed by the generator and the generator transformer as indicated in Table 13.8.

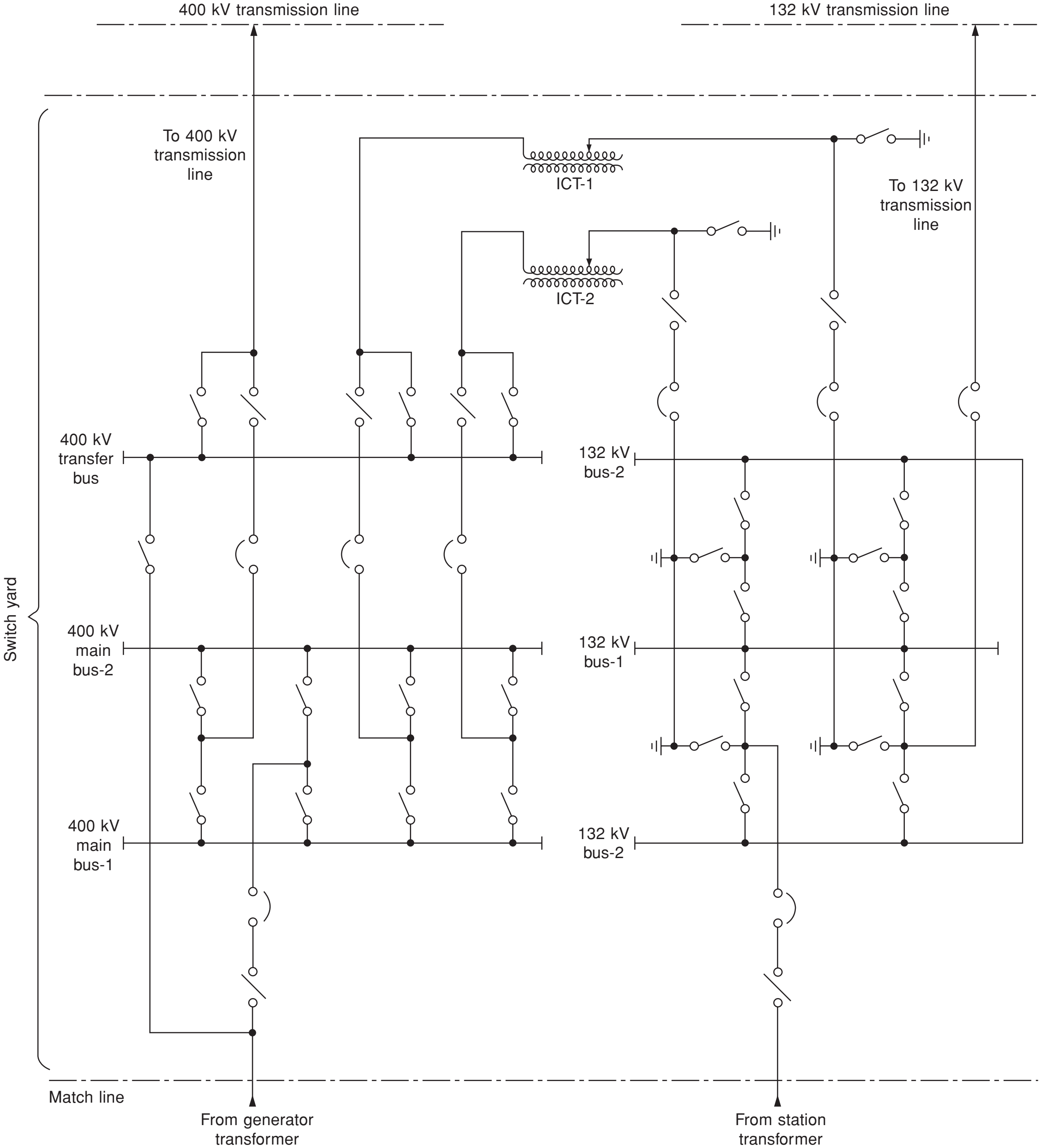


Figure 13.21 *(Contd.)*

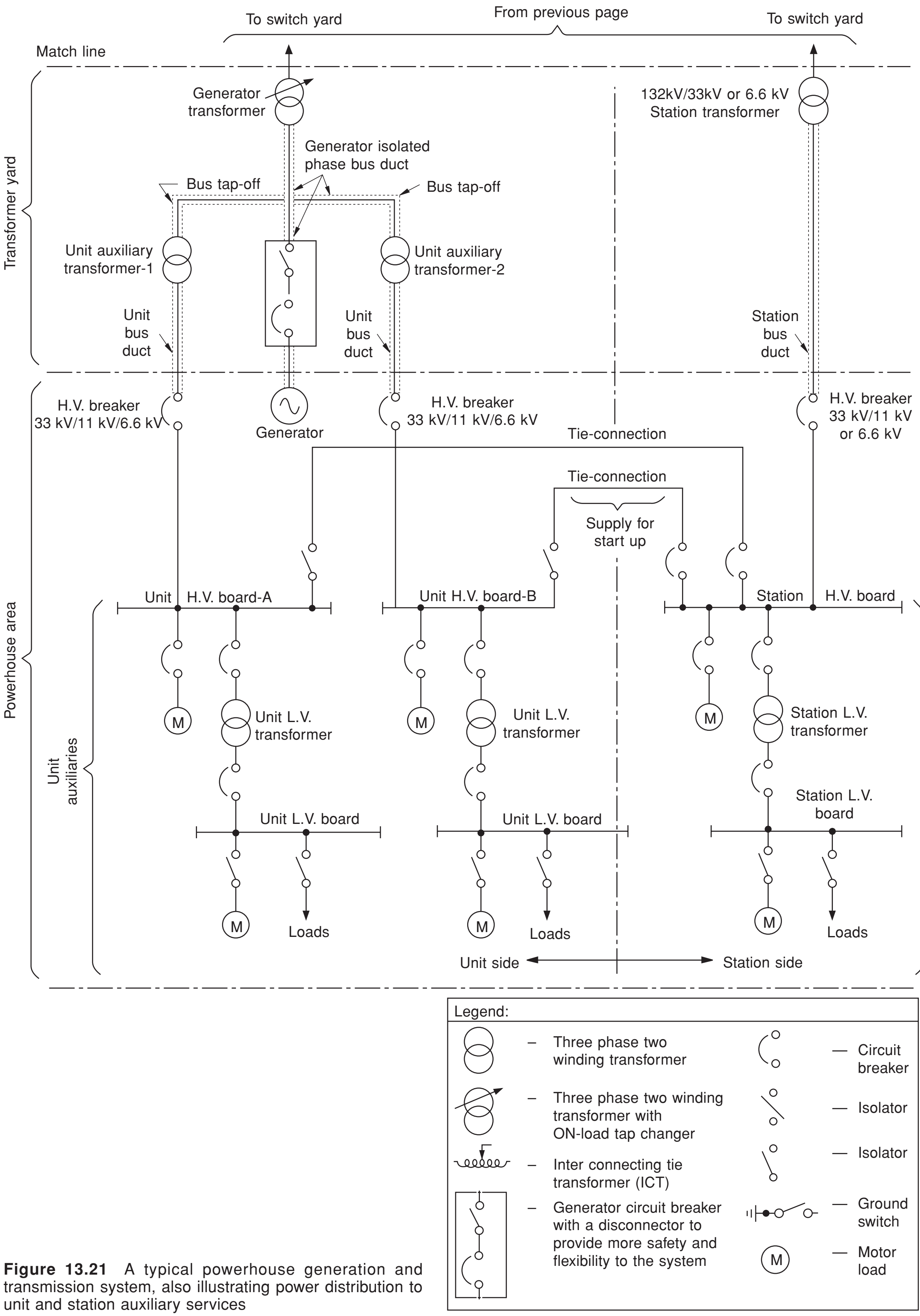


Figure 13.21 A typical powerhouse generation and transmission system, also illustrating power distribution to unit and station auxiliary services

6 One second or three second system

We have mentioned two systems, 1 second and 3 second. A choice of any of them would depend upon the location and the application of the equipment and criticality of the installation. Generally speaking, it is only the one second system that is in practice.

Validity of a three second system

Speaking generally in today's scenario a three second system has only historical significance*. Until 1960s or so this was in practice, because then the fault level of a system used to be low and interrupting devices were capable to interrupt these low level, high duration faults. With the rising capacity of the power networks over the years and their consequent higher fault levels, this practice is no longer valid in view of the following,

- the interrupting devices with such high fault levels at all high voltages are not easily available (unless designed and manufactured specially at exorbitant cost).
- it is essential to contain the damage at the point of fault by containing the heat generated. Otherwise the heat generated will be so enormous that it may be catastrophic. Any high magnitude fault must be cleared as fast as possible preferably within 0.5 second. It can be achieved by providing suitable primary and backup protective relays for fast detection and clearance of faults. The primary system clearing it in about 80–120 ms including the relay and breaker opening times (Section 24.9.1).
- to prevent prolonged voltage dips (while the fault lasts) in other circuits.
- save the system from an instability.

It is therefore not advisable to let such high level faults persist for such a long duration (three seconds). For all practical purposes therefore a one second system alone is now in practice universally, barring some exceptions in medium voltages as noted.

7 Rated momentary peak value of the fault current

For the sake of simplicity above we discussed a symmetrical fault condition avoiding the d.c. component. Whereas a fault current on a power system is normally asymmetrical as discussed next, and is composed of a symmetrical a.c. component $I_{sc(r.m.s.)}$ and an asymmetrical sub-transient d.c. component I_{dc} (Figure 14.5). The forces arising out of I_{sc} are referred to as electromagnetic and those by asymmetry, i.e. I_{dc} as dynamic. The cumulative effect of this, $I_{ssc}\left(=\sqrt{I_{sc}^2+I_{dc}^2}\ \text{(Section14.3.6)}\right)$ is electro-dynamic and is quite significant. It requires adequate care while designing a current-carrying or supporting system. Switching devices, other current carrying components and their mounting structures, such as the busbar systems in a PCC, MCC or a bus duct etc. must be suitable to withstand such stresses during a short-circuit. It is therefore of vital importance to take account of this asymmetry and to determine this to form an important design parameter for switching devices and all current carrying systems.

The peak value of a fault current will depend upon the content of the d.c. component. The d.c. component will depend upon the p.f. of the faulty circuit and the instant at which the short-circuit commences on the current wave. (Refer to Figure 13.27, illustrating the variation in asymmetry with the p.f. of the faulty circuit. For ease of application, the asymmetry is represented as a certain multiple of the r.m.s. value of the symmetrical fault current I_{sc}.)

The content of asymmetry may decay quickly and may exist in the system for just three or four cycles from the commencement of the fault, depending upon the time constant, τ, of the circuit. The time constant, τ, is the measure of the rate of decay of the d.c. component, and is the ratio of the system reactance, L, to the system resistance R, i.e. L/R. A large L/R will indicate a high time constant and a slow rate of decay and vice-versa, as illustrated in Figure 13.22. The asymmetry is therefore measured by the peak of the first major loop of the fault current (which may occur in any of the phases, as it has occurred in phase Y in the oscillogram shown in Figure 13.23). The subsequent loops will be smaller and less severe and thus the significance of the first loop. This is referred to as the momentary peak value of the short-circuit current for the most severe fault conditions, such as at extremely low p.fs. (R/X_L being very low) when the recovery voltage may be the maximum. These values are given in Table 13.11 in the form of likely multiplying factors for different symmetrical r.m.s. values of fault currents, I_{sc}, according to IEC 60439-1 for LV and IEC 60694 for HV systems and are drawn in Figure 13.22. These values are almost the same as provided by ANSI-C-37/20C as well as in Table 28.1. The exact values of

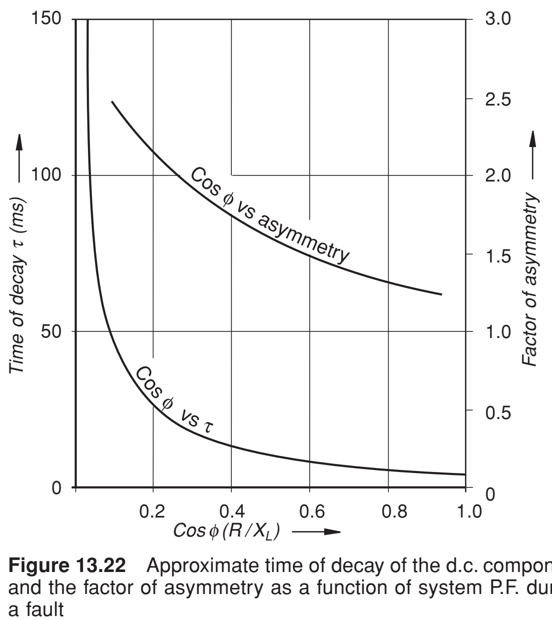
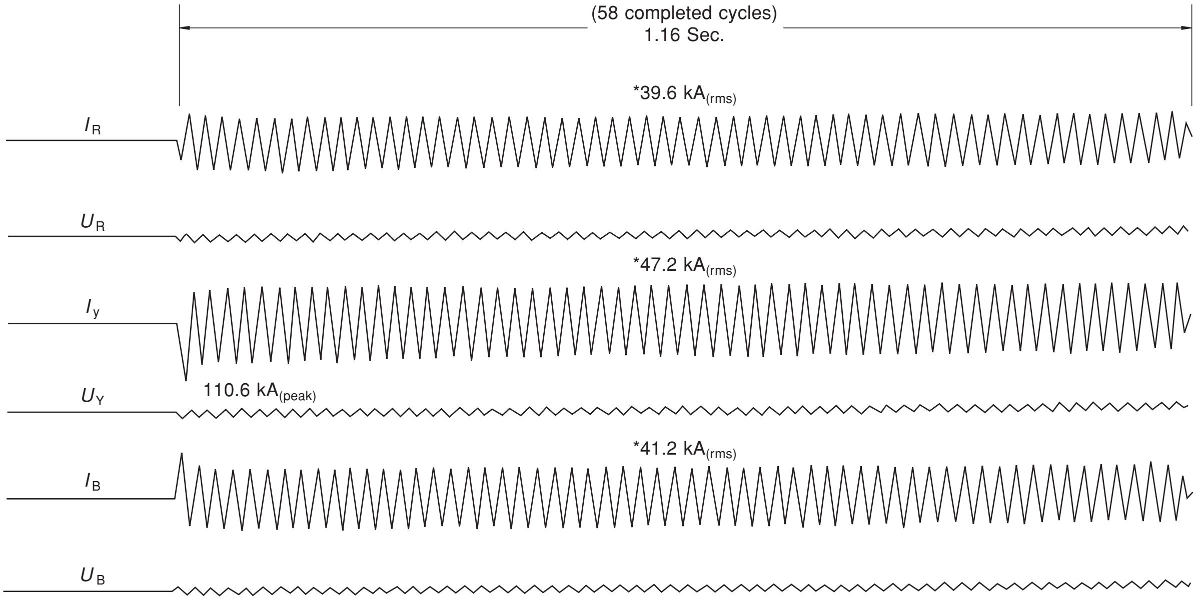


Figure 13.22 Approximate time of decay of the d.c. component and the factor of asymmetry as a function of system P.F. during a fault

*Barring some countries or applications where it may still be prevalent but limited up to medium voltages only.



*Just for illustration as the variation in phase currents should not be more than 10% of the average current as per IEC 60439-1

Figure 13.23 Oscillograms of an actual short-circuit test carried out on a power distribution panel

Table 13.11 Multiplying factors to obtain the momentary peak (maximum r.m.s. or dynamic) values of the short-circuit currents including the sub-transient d.c. component at different power factors (R/X_L)

Prospective short-circuit or short-time current; I_{sc} kA(r.m.s.) (symmetrical breaking current)	*Factor of asymmetry to obtain the peak short circuit or making current I_M*	*Cos ϕ (R/X_L)*
(a) For LV systems		
Up to 5	1.5	0.7
Above 5 to 10	1.7	0.5
Above 10 to 20	2.0	0.3
Above 20 to 50	2.1	0.25
More than 50	2.2	0.2
(b) For HV systems	Min. 2.5	–

Note
For CTs this multiplying factor has been specified as 2.5 for all voltage systems, as in IEC 60044-1. See also Section 15.7 for metering and protection current transformers.

this factor may be estimated by creating a short-circuit condition and obtaining an oscillogram. For details refer to Figure 13.23.

Notes
1 The rated momentary peak value of the fault current, I_M, will relate to the dynamic rating of an equipment. It is also known as the making current of a switching device and defines its capability to make on fault.
2 The peak value of the asymmetry is considered to determine the electrodynamic stresses to design the mechanical system and the supporting structure for the current-carrying components.
3 A breaker will not trip instantly when a fault occurs, but only after a few cycles, depending upon the actuating time of the protective relays and the breaker's own operating time. It will therefore generally trip only during the transient state of the fault. The breaking capacity of an interrupting device, unlike its making capacity, is therefore defined by the rms value of the transient state fault current, i.e. by I_{sc} (Table 13.9).
4 When designing a current-carrying system it is the r.m.s. value of the fault current, I_{sc}, that is relevant to determine the thermal stresses ($\propto I_{sc}^2$) during a fault, to choose the correct material and size of the current-carrying components. (The duration of asymmetry is too short to cause any significant heating of the current-carrying components.)

Example 13.6
For a 50 kA (r.m.s.) fault level on an LV system, the momentary peak value of the fault current, I_M, will be = 50 × 2.1 = 105 kA.

8 Causes of asymmetry

A current wave propagating symmetrically about its zero axis, i.e. when the envelopes of the peaks of the current wave are symmetrical about its zero axis, is termed symmetrical (Figure 13.24) and a wave unable to maintain this symmetry is termed asymmetrical (Figure 13.25).

The p.f. during a short-circuit as noted earlier is quite low, and is normally of the order of 0.1. The current will now lag the voltage by nearly 84° (Figure 17.11(c)). To analyse the shape of a current wave on a short-circuit, consider the following conditions that may occur at the instant of the fault:

1 When the short-circuit occurs at a current zero, i.e. when the applied voltage is almost at its peak, the voltage and current waves will follow Figure 13.19, the current lagging the voltage by almost 84°. The current will now be almost symmetrical.
2 When the short-circuit occurs at a voltage zero the

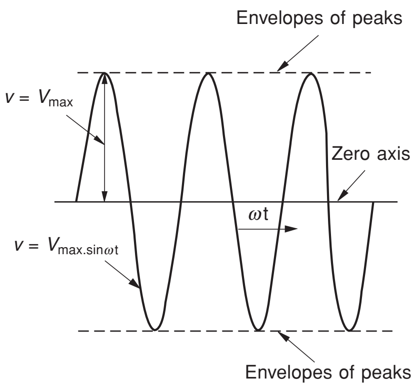


Figure 13.24 A symmetrical waveform

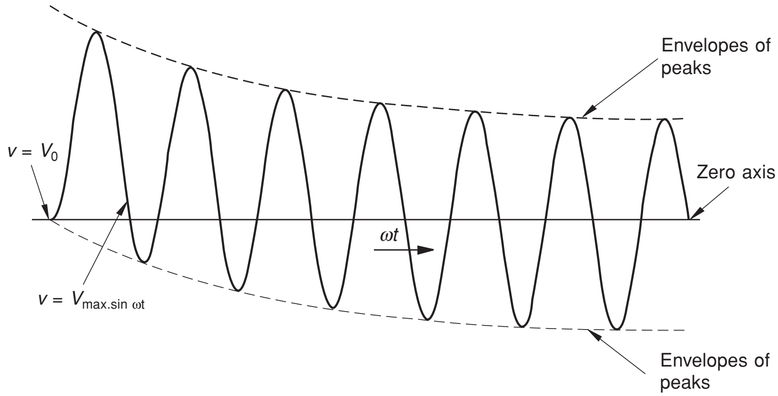


Figure 13.25 An asymmetrical waveform

current will also commence at zero. This is an unusual situation when both the voltage and the current waves commence at zero and yet cannot propagate in phase with each other, in view of the current lagging the voltage by almost 84°. This situation is resolved by a shift in the zero axis of the current wave by almost 84°, as illustrated in Figure 13.26. Now it is able to fulfil its above condition again. The current will now be fully asymmetrical.

3 Let us consider a more realistic situation, when the short-circuit may occur somewhere between the above two conditions.

Supposing the current and the voltage waves both have some value on their respective waveforms at the instant of short-circuit. The current will again tend to become somewhat asymmetrical but not fully. The content of asymmetry will depend upon the instant at which the short-circuit condition occurs on the current wave and the p.f. of the faulty circuit (Figure 13.27). The higher the recovery voltage at the instant of fault, the lower will be the asymmetry (at V_m, the d.c. component will be zero) and vice versa (at V_0, the d.c. component will be the maximum).

It is observed that there may be asymmetry in the system as long as the short-circuit condition lasts, as illustrated in Figure 13.20, i.e. up to the opening of the interrupting device. (For opening times of interrupters, refer to Table 19.1.) But the content of the asymmetry may be quite feeble after three or four cycles. However, if the short-circuit condition still prevails, such as when conducting a short-circuit test up to the desired duration of 1 or 3 seconds, the short-circuit current, although theoretically asymmetrical until the test period, may be regarded as symmetrical (having reached its steady state) after three or four cycles. The content of asymmetry is ignored after three or four cycles for all calculations and practical purposes. In fact, a d.c. component less than 50% that of the peak symmetrical component of the fault, current $\sqrt{2}I_{sc}$, at any instant during the course of short-circuit condition may be ignored. In other words, the relevance of the asymmetry may be considered only up

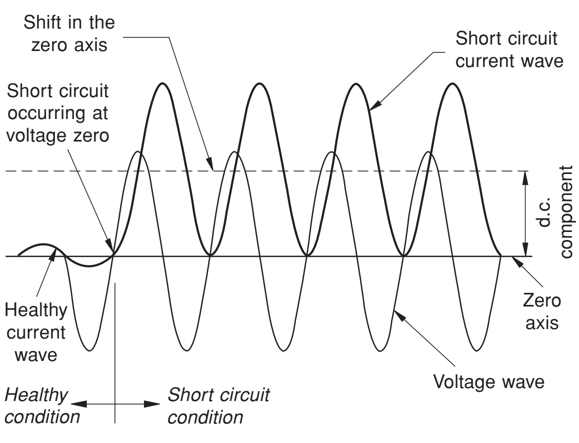


Figure 13.26 Illustrating a shift of nearly 90° (drawn at 90° for ease of illustration) in the current wave at nearly 0.1 PF, fulfilling the condition of current lagging the voltage by nearly 90° yet rising together at zero voltage (minimum applied voltage)

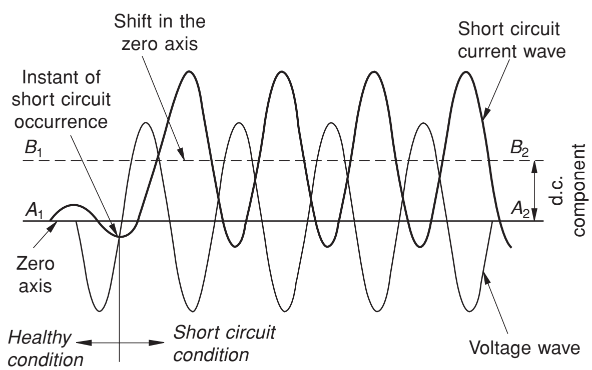


Figure 13.27 Approximate illustration of a short-circuit condition occurring when both voltage and current waves are not at their natural zeros. Current shifting its zero axis from A_1 A_2 to B_1 B_2 to rise from zero again at the instant of short-circuit

to the first peak, as the immediate subsequent peaks may also be less than 50% of the peak value $\sqrt{2} I_{sc}$ ($I_{dc} < 0.5 \sqrt{2} \cdot I_{sc}$) at that instant.

The generation of an asymmetrical current on an a.c. system, leads to the inference that a short-circuit condition will give rise to a d.c. component due to a shift in its zero axis. During the sub-transient state the value of the asymmetrical current will be the phasor sum of the symmetrical I_{sc} and the asymmetrical I_{dc}, current components. For details refer to Section 14.3.6.

13.4.2 Service conditions

Ambient temperature, altitude and atmospheric conditions at the place of installation of electrical equipment are considered to be the service conditions for the equipment to operate and perform its duties. Every electrical equipment is designed for specific service conditions and variations may influence its performance. Below we analyse the influence of such non-standard service conditions on the performance of equipment and the required safeguards to achieve its required performance.

Ambient temperature

The rating of an indoor or outdoor switchgear assembly is referred to at an ambient temperature of 40°C. For a higher ambient temperature the rating of the assembly will be reduced in the same proportion as for the busbar systems and as shown in Table 28.3.

Altitude

For assemblies using the surrounding air as the insulation and cooling medium

The standard altitude for an LV switchgear assembly is 2000 m and for HV 1000 m, as in ANSI-C-37.20C and IEC 60439-1. At altitudes higher than this, the normal increase in temperature will become greater and the dielectric strength less for all assemblies using air as the insulating and cooling medium. For applications at higher altitudes, therefore, the derating factors as noted in Table 13.12 must be applied to obtain the reduced level of dielectric strength, i.e. one-minute power frequency voltage withstand, impulse voltage withstand and the continuous current rating etc. to which level the switchgear assembly will now be rendered to. To achieve the original level of dielectric strength, the insulation system of the switchgear assembly will have to be improved by the same degree as the derating. This can be achieved by increasing the clearances and the creepage distances to ground and between phases as discussed in Section 28.5.2 and Tables 28.4 and 28.5.

To achieve the original value of the continuous current, the size of the current-carrying components may also be increased to carry the higher amount of current in proportion to the derating.

Table 13.12 Derating for higher altitudes for metal enclosed switchgear assemblies and bus systems

Altitude (m)		*Derating factors*	
LV systems	*HV systems*	*Dielectric strength*	*Continuous current rating*
2000	1000	1.0	1.00
2600	1500	0.95	0.99
3900	3000	0.80	0.96

Source ANSI C-37.20.2 and C-37.23

Notes

1 Intermediate values may be obtained by interpolation.
2 No derating is applicable in case of insulated switchgear (GIS) assemblies.

Atmospheric conditions

A normal enclosure is meant for a reasonably clean atmosphere and a relative humidity not more than 50% for LV and 95% for HV indoor enclosures. Where the atmosphere is laden with fumes or steam, saline or oil vapours, heat and humidity, excessive dust and water or contaminated with explosive and fire hazardous gases, vapours or volatile liquids (Section 7.11) a special enclosure with a higher degree of protection is required as in IEC 60529 or IEC 60079-14. For non-hazardous areas, the enclosure can be generally one of those discussed in Tables 1.10 and 1.11, and when required can be provided with special treatment to the metallic surfaces. For hazardous areas, however, special enclosures will be essential as discussed in Section 7.11.

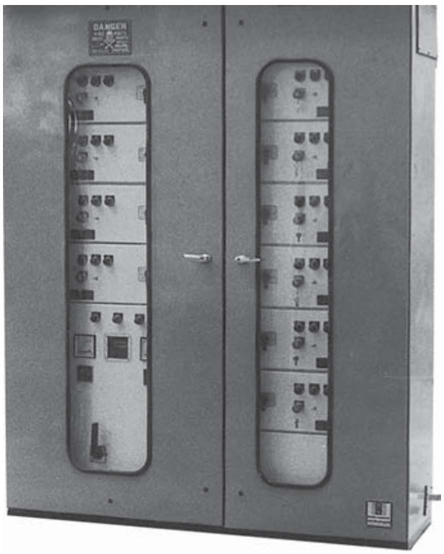
In outdoor type switchgear or controlgear assemblies the normal practice is to provide a double door in the front to house the front panel and protect the door knobs, meters, lights, pushbuttons, reset knobs or other accessories mounted on the door and thus prevent water or dust leaking through joints, knockouts and fitments etc. It is also recommended to have a canopy on the top of the enclosure to protect the panel from direct rain. Figures 13.11 and 13.28 illustrate this type of construction.

Flame- or explosion-proof assemblies (Type Ex. d)

For hazardous areas flameproof enclosures alone are recommended, except in areas with moderate intensity of contamination and where such assemblies are located away from the affected area and in a separate well-ventilated room, when pressurized enclosures may also be safe. The reason for this precaution is that frequent arcing takes place within the enclosure on each switching of a contactor, switch, breaker or an OCR etc. and also during operation of auxiliary contactors.

The classification of gases, vapour and volatile liquids according to their ignition temperatures has been given in Table 7.4. The basic requirements of these enclosures, which remain the same as for motors conforming to IEC 60079-1, are also discussed in Chapter 7. Some of the vital requirements that a flameproof controlgear or switchgear assembly must fulfil are, however, as follows:

With front doors open



With front doors closed

Figure 13.28 A typical compartmentalized outdoor-type panel (courtesy: Atoz Power Systems)

1 To prevent an electric arc or flame from the enclosure escaping to the atmosphere.
2 To withstand, without distortion, an explosion, within the enclosure.

An internal explosion is normally a consequence of absorption of inflammable substances during a delayed shutdown on a switch-on. When an enclosure is switched OFF after normal running, the internal air cools and absorbs contaminants from the atmosphere. As a switch, a contactor or a breaker produces an arc during a switching operation, an explosion may occur within the enclosure on a re-switching. It is also possible that when the enclosure door is opened to check, test or replace a component, contaminants may have entered the enclosure. It is also likely that on a re-closing of the feeder door, the closure is not perfect due to human error and contaminants have leaked into the enclosure. All this may lead to an explosion on a re-switching.

Since it is not practical to manufacture a flameproof enclosure due to its size and bulk and the number of knockouts and openings on the doors for switches, metering, indicators, and pushbuttons (PBs) etc., it is common practice to locate these assemblies some distance from the affected area in a separate well-ventilated room. Depending upon the location and intensity of contamination, it may be permissible to meet the requirement by using a pressurized enclosure by maintaining a positive pressure inside the enclosure similar to that for motors (Section 7.13.3). When there are many switchgear assemblies, the room itself can be pressurized, which is safer and easier. Small enclosures, however, such as a PB station, switch or a switch fuse unit or an individual starter unit etc., which can be easily made of MS plates or cast iron, as discussed in Section 7.13, can be mounted in the hazardous area while the main MCC can be installed in the control room, away from the contaminated area and from where the process can be monitored.

Note
Avoid soldering of cable and wire terminal joints at such installations, which may loosen with temperature and time and cause arcing.

Excessive vibrations and seismic effects

Installations prone to heavy vibrations and shocks such as on the mounting platform near a large power-generating unit, on a ship, locomotive and similar installations may require provisions to absorb shocks and damp vibrations to prevent loosening of components and wire connections in a switchgear or a controlgear assembly. Some economical methods to achieve this can be by providing:

- Anti-vibration pads at the foundation
- A rubber pad between the bottom of the assembly and its base or
- Mounting pads below the base frame.

But shocks of a seismic nature are different and may be more violent. They may require a special steel structure, forming the switchgear or the controlgear assemblies, to sustain the shocks without damaging or loosening components and wires mounted inside the assemblies. It may be possible to achieve this by using thicker sheets for the enclosures and providing additional reinforcement, wherever necessary, and exercising special care in selecting and fixing the hardware. The degree of reinforcement and other provisions to make the whole assembly and inside mounts suitable for a particular intensity of seismic effects will depend upon the probable seismic conditions in that area. This subject is dealt in with more detail in Section 14.6.

Note
One may observe that all the above special service conditions are generally the same as for the rotating machines discussed in Section 1.6.

13.5 Deciding the ratings of current carrying equipment, devices and components

The rating of current-carrying equipment (switchgear assemblies, such as for the main bus system), devices (breakers, switches and contactors) and components (connecting links and wiring etc.) is defined by two parameters:

1 **Thermal rating or continuous current rating** This takes account of heat losses ($\propto I_r^2 \cdot t$, t being the time to reach thermal equilibrium), as generated during a long continuous operation under rated conditions. In breakers, switches and contactors, it will also define their duty cycle, i.e. the type of duty they may have to perform (Section 12.10 and Table 12.5).

To the basic current requirement is applied the derating factors for various service conditions, as noted in Section 13.4.2. The equipment, devices and components may then be chosen to be as close (nearest higher) to this rating as possible from the available standard ratings. Based on these ratings are calculated, the minimum cross-sectional areas of the other current-carrying parts used in the circuit, such as inter-connecting links and the cables.

2 **Short-time rating** This will define

- The electrical rating on a fault or short-term high current thermal effects, expressed by $\alpha I_{sc}^2 \cdot t_{sc}$, i.e. short-circuit current (I_{sc}) and its duration (t_{sc} – 1 or 3 seconds), (see Section 13.4.1(6)).
- The mechanical endurance of the current-carrying parts of all the equipment, bus system, devices and components, used in a particular circuit as well as the load-bearing members and supports on which they are mounted. The electrical parts of a device (breakers and switches, etc.) are the responsibility of the component manufacturers. The manufacturer of the switchgear assembly is responsible for the busbar systems, metallic links and wires.

The mechanical requirements of the load-bearing members, supports, busbars and metallic links in the incoming circuit will depend upon the electrodynamic forces arising out of the first major peak of the fault current, as discussed in Section 28.4.2. This is not, however, applicable to devices that are current limiting as well as the circuits and its components that are protected by it. These devices isolate the faulty circuit long before the fault current reaches its first highest peak. Yet the short-time rating for the incoming circuit (as the outgoing circuits may not experience these faults), should be selected from the standard short-time ratings only, as defined in Tables 13.7 and 13.10. For this short-time rating is then calculated the minimum cross-sectional area of the current-carrying components. To determine the cross-sectional area for this short-time rating and decide the mounting structure, supports and hardware etc. for the busbars, a brief procedure is described in Example 28.12.

Both ratings, thermal and short-time, will define the cross-sectional area of the current-carrying components. The more severe of the two will then prevail. In the following text we explain the procedure to assign the short-time current rating to equipment, a device or a component.

13.5.1 Assigning a short-time rating

The bus system of a switchgear assembly, its inter-connecting links and wires are the protected type components, whereas an interrupter (breaker, switch or a fuse) may be a protecting or protected type, depending upon their application and location in the circuit. A contactor and an OCR are therefore protected devices in the same context, for they provide no short-time protection. A protecting device may become protected when it is also provided with a back-up protection.

A breaker, usually an MCCB or an MCB on an LV system, can be provided with back-up HRC fuses to enhance their short-time rating. This may be done when the available MCCBs or MCBs possess a lower short-time rating than the fault level of the circuit they are required to protect, and make them suitable for the fault level of the circuit. But this is not a preferred practice when high rupturing capacity interrupters are available unless it is chosen for economic consideration. As a rule of thumb, the device that is protecting must be suitable to withstand electrically and endure mechanically the system fault current for a duration of one or three seconds, according to the system design.

The duration, however, is no criterion for a current limiting type protecting device, and a protected equipment, device or component can have a short-time rating commensurate with the tripping characteristics of the protecting interrupter. Accordingly these two types of tripping characteristics, delay tripping and current limiting types are explained below.

Delay tripping

The breakers (OCBs, MOCBs, ABCBs, SF_6 and VCBs) for HV and ACBs and MCCBs* for LV systems are devices that have a tripping time of more than a cycle on fault. The tripping time can vary from 1 cycle (20 ms) to 5–6 cycles (100–120 ms for 50 Hz systems), depending upon the type of interrupter as discussed in Chapter 19 and noted in Table 19.1.

This time allows the fault current to reach its peak and therefore all the equipment, devices and components

*MCCBs
(i) When they are normal duty as considered here.
(ii) They are also available in the current limiting type. When current limiting, they will not fall in this category.

protected by such a device must be suitable for the full fault level of the system. While the tripping time is usually in milliseconds the duration of fault, t_{sc}, is considered as one or three seconds. The longer duration than necessary is to account for the various time lapses that may occur before the actual tripping. When the tripping is electrical it may involve a trip coil adding to the mechanical tripping time, actuating time of relays, minimum time of tripping of interrupter itself (Table 19.1) and some safety margins. While the actual tripping time may still be quite low, it is customary to design a system for one or three* seconds and for which is designed all the equipment, devices and components, protected by such a device.

The value of short-time rating** ($I_{sc}^2 \cdot t_{sc}$) of the system may now exceed the thermal rating of some of the equipment, devices and components, i.e. $I_{sc}^2 \cdot t_{sc}$ of the system > thermal rating of the components. This condition may be more likely in smaller rating components, particularly 600 A and less (such as for busbars), than larger ones. At higher currents, the natural thermal rating of the component itself, due to the higher cross-sectional area of its current carrying components, will become higher than the required short-time rating. The short-time rating will remain the same for a particular fault level of a system, irrespective of the current rating of the circuit. For more details refer to Section 28.4.1. Whenever the short-time rating of the system exceeds the thermal rating of the component, a larger area of cross-section of the main busbar system and the other current-carrying components will become necessary.

Figure 13.29 illustrates a simple distribution system and location of the main buses, devices and components to define the current ratings of all such devices and components under different operating conditions. The ideal current ratings of these components are given in Table 13.13 for an easy illustration.

The fault currents also develop electrodynamic forces, F_m, as in Equation (28.4) due to the sub-transient d.c. component. These forces play an important role in the mechanical design of the interrupting device, the load-bearing and mounting structures for the interrupter, the bus system, and the hardware used in a switchgear assembly. All such mechanical parts, supports and hardware should be adequate to withstand such forces when they arise. A procedure to arrive at the ideal size of the current-carrying components, mounting structure, type of supports and hardware etc. is discussed in detail in Example 28.12.

If the short-time rating of the interrupting device is higher than the fault level of the system, which is the case with modern interrupting devices, the fault level of the system alone will prevail for the busbars, components and hardware. For example, for a system fault level of 50 kA, if the interrupter used is of 65 kA short-time rating, the bus system and all associated components will be designed for 50 kA only.

Current limiting type

Examples are HRC fuses (both LV and HV) and MCCBs and MCBs (LV only), which are available with current limiting features and are in extensive use. The tripping time of these devices is extremely low and much less than one half of a cycle of the current wave. They therefore do not allow the fault current to rise to its prospective peak. The protected devices and components can thus be selected based on the let-out energy of such devices on fault, which is extremely low, than the fault level of the system. If

I_{sc} = system fault level (r.m.s. value)

t_{sc} = pre-arcing time of the HRC fuses or tripping time of MCCBs or MCBs, which would be much less than 5 ms (less than one quarter of a cycle for a 50 Hz system; see Figure 12.17 for more clarity)

then the let-out energy of the current limiter,

$$\propto I_{sc}^2 \cdot t_{sc}$$

If I_e is the equivalent 1-second fault current

$$\text{then}\quad I_e^2 \cdot 1 = I_{sc}^2 \cdot t_{sc}$$

$$\text{or}\qquad I_e = I_{sc}\sqrt{t_{sc}}$$

Since t_{sc} will be too low (< 5 ms for a 50 Hz system) I_e will be much less than 7% of I_{sc} in all situations. To assign a short-time rating to the protected devices and components in such cases is therefore of little relevance. As noted already, current is the cause of heat, for which is assigned the thermal duty of a current-carrying device, component or part. Also note the following:

1 Current limiting devices need not be protected, since they are already very fast acting and, hence, self-protected.
2 But they should also be rated for the same fault level for which the system is designed as they are connected directly to the system. This is a safety requirement.
3 Similarly, in a draw-out switchgear assembly, the I/C and O/G power contacts of a module and its mounts (insulators and supports) if are already protected by current limiters may be suitable only for the thermal rating of their feeders.
4 When such devices are used at more than one location in a circuit, their ratings must be meticulously co-ordinated to ensure isolation of the faulty circuit alone. Discrimination for HRC fuses is provided in Section 12.4.2. Similar procedure can be adopted for current limiting MCCBs also. A more accurate discrimination can, however, be achieved through energy based discrimination described briefly under Section 13.5.2 for current limiting MCCBs.
5 A current-carrying device or component in a distribution network may be subjected to varying degree of electrodynamic stresses, depending upon its location with reference to the network. Referring to Figure 13.29, the circuits away from the source of supply are subjected to lower stresses than the circuits nearer to it. Accordingly, the co-ordination is done between the protective devices, used in the upper and lower streams of circuits, to ensure that only the faulty circuit is isolated, rather than isolating other circuits in the upper stream.

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*Usually one second, see Section 13.4(6)

**I_{sc} refers to r.m.s. value

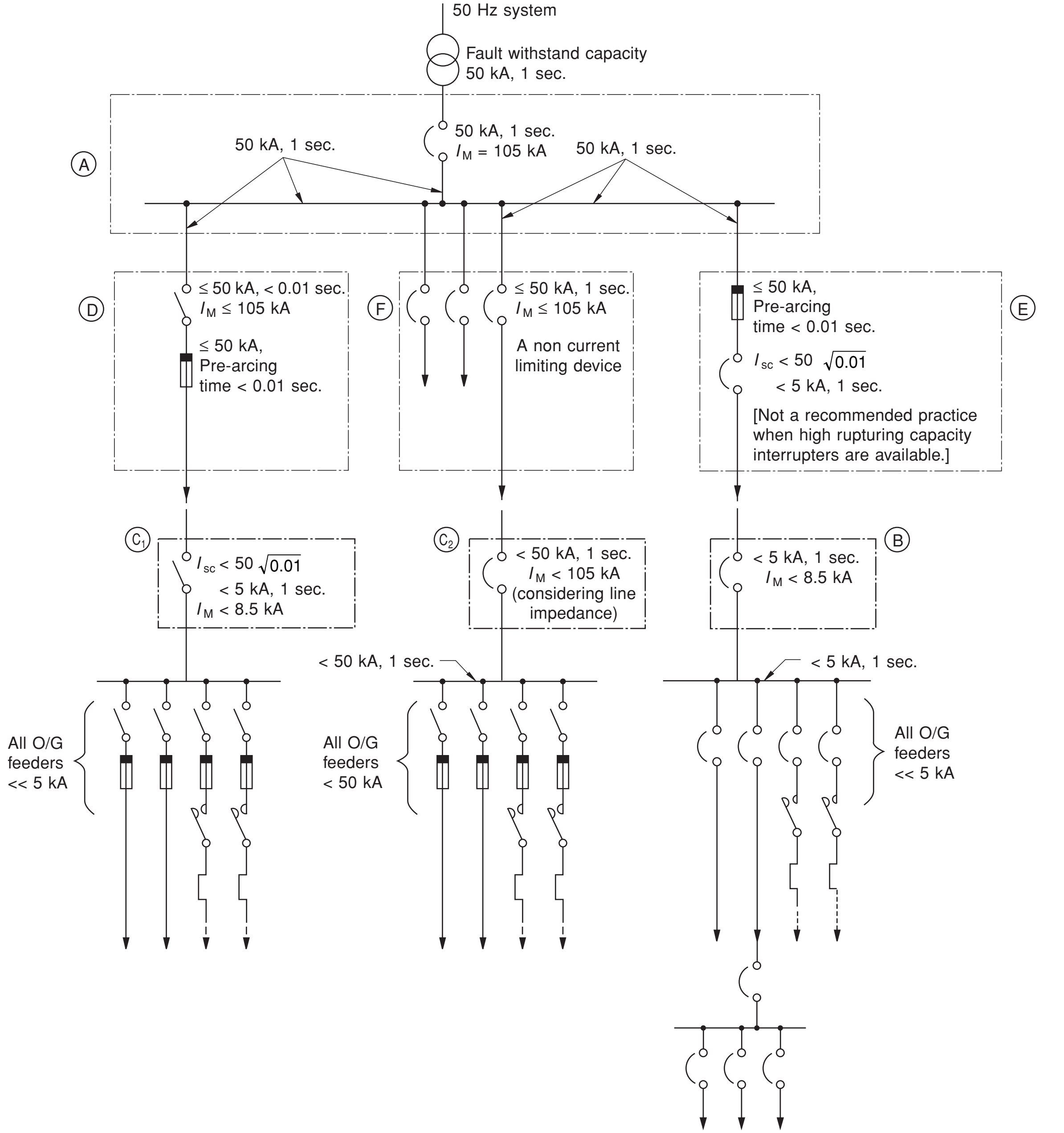


Figure 13.29 An LV power distribution scheme illustrating the procedure to assign fault withstand capacity to a device, component or a bus system

Notes on Table 13.13

1 An isolator, such as at locations C_1 and C_2 in Figure 13.29, may sometimes be used to isolate the circuits it is feeding, say, for maintenance or repairs. This isolator is simply a switch and provides no protection to the circuits. For a fault on the outgoing side, the individual outgoing feeders must have their own protection. For a severe fault elsewhere in the system, there must be a protective feeder closeby, in the upper stream.

2 **Role of an OCR:** this is only an over-current protection device and does not provide short-circuit protection. The maximum it can operate is under a locked rotor condition of a motor, in which case the maximum current may not exceed six to seven times its rated current, which is moderate and far less than a short-circuit condition. Hence, it is not considered in Table 13.13.

3 Similarly, a contactor is a simple circuit making and breaking device, and is protected by other protective devices used in association with it. It has no role in

Table 13.13 Brief guidelines to assign the short-time rating to a component used in a switchgear assembly

	Components						
	← Interrupting devices →					← Equipment and components →	
	Application						
	When used as a protective device (as incomer)		*When used as a protected device (as outgoing)*[c]		*When used as an isolator (as incomer)*	*As protected parts*	
Parameters (1)	Tripping time > 1 cycle (2)	Tripping time < half cycle (3)	Tripping time > 1 cycle (4)	Tripping time < half-cycle (5)	– (6)	Interrupter tripping time > 1 cycle (7)	Interrupter tripping time < half cycle (8)
Type of devices	OCBs[a], ACBs, MCCBs in LV and MOCBs[b] ABCBs[b], SF_6 and VCBs in HV	MCCBs, MCBs in LV and HRC fuses in both LV and HV	As in column 2	As in column 3	Switching device locations C_1 and C_2, as shown in Figure 13.29	Main bus, its feeding tap-offs and interconnecting links or cables etc. and all outgoing links, interconnecting devices that are also connected on the main bus such as shown at Section F, Figure 13.29.	All outgoing connections by solid links or cables
1 Short-time rating or symmetrical fault level (r.m.s.) I_{sc}	I_{sc}	I_{sc}	I_{sc}, if connected on the main bus, otherwise $< I_{sc}$ depending upon the circuit impedance		Depending upon the protective feeder on the upstream. Refer to Figure 13.29	I_{sc}	No relevance
2 Duration of fault t_{sc}	1 or 3 seconds[d]	< half cycle or < 5 ms for a 50 Hz system	1 or 3 seconds[d]	< half-cycle or < 5 ms for a 50 Hz system	1 or 3 seconds[d]	1 or 3 seconds[d]	–
3 Making capacity I_M	As in Table 13.11	–	As in Table 13.11	–	As in Table 13.11	–	–
4 Endurance of supporting and mounting structure, load-bearing members and hardware	According to electrodynamic forces, $F_m \propto I_M^2$ Equation (28.4)	–	As in column (2)	–	As in column (2)	As in column (2)	No additional reinforcement of members or supports necessary
5 Cross-sectional area of current-carrying metallic links or cables	Taken care of by the manufacturer of the devices					(a) For mechanical endurance according to F_m (Section 28.4.2) (b) For electrical endurance $\alpha I_{sc}^2 \cdot t_{sc}$ (Section 28.4.1) and (c) For maximum thermal rating $\propto I_r^2 t$ of the feeder, whichever is higher of *b* and *c*. (t = time required to reach the thermal equilibrium)	As per maximum thermal rating of the feeder.

Figure 13.29 illustrates a typical power distribution scheme to assign ratings to the various devices, components and busbar systems.

[a]Use of these breakers is gradually waning in the light of more advanced technologies available in an ACB and MCCB.

[b]Use of these breakers is also waning in the light of more advanced technologies available in SF_6 and VCBs (Section 19.5).

[c]These protect the circuits in the lower stream and are protected by a device in the upper stream such as feeders D and E in Figure 13.29.

[d]Normally only a 1-second system is in use. The 3-second system is severe, for which protective devices in certain ratings may not be possible or may become prohibitively costlier to produce. The 3-second system may, however, be used for a generator circuit to protect the generating source from a fallout on a fault elsewhere in the system. Also see Section 13.4(6) on validity of 3-second system.

the decision making for the current rating of other components or devices used in the circuit. Hence it is not considered in the table.

4 **Diversity factor:** this applies to column 7 of Table 13.13. Whenever a bus section has to feed a number of outlets, one can apply the diversity factor as discussed in Section 13.4.1(4) to optimize on the size of busbars and also the size of the main incoming feeder (Example 13.1).

5 **Service conditions:** on all the ratings so determined, one may apply the applicable service factors as noted in Section 13.4.2 to arrive at the most appropriate sizes of components, bus sections, etc.

13.5.2 Energy based discrimination (for current limiting breakers)

In a power distribution network having a number of load points down the stream and the protection is through current limiting MCCBs, it becomes imperative to have a judicious discrimination between the upstream and the down stream feeders through their respective protective devices. It is to ensure that all healthy feeders remain operational at all levels of the network during a fault and only the faulty feeder of the down most stream trips. A judicious discrimination would ensure maximum continuity of supply. The discrimination is easy for a small network and becomes complex as it gets large with a number of load points such as shown in Figure 12.20. With this in view some manufacturers have introduced an innovative idea to achieving an easy and more reliable discrimination between feeders through energy based discrimination. The concept behind this is the tripping energy, I^2t that remains constant for a breaker. Therefore higher goes the fault current shorter becomes the trip time making discrimination rather easy. The let through energy of the breakers in different streams can thus be set such that for the same I^2t up stream trip time is more than the down stream.

The basic data remain the same as for standard thermal curves for HRC fuses (Figures 12.18 and 12.19). Similar curves are established in terms of prospective fault current, I_{sc} (rms) as abscissa and energy released, I^2t as ordinate on a log-log graph. The curves are superposed with straight lines for different interrupting times, t and cut-off currents as a function of prospective fault current, I_{sc}. The procedure to establish these curves is similar as for establishing a conventional thermal curve (Section 3.6) substituting energy for tripping time. A typical curve is shown in Figure 13.29(a). From this curve one can infer the following:

Point a - threshold level for tripping –10 *Ir*.
- tripping time – 50 ms.

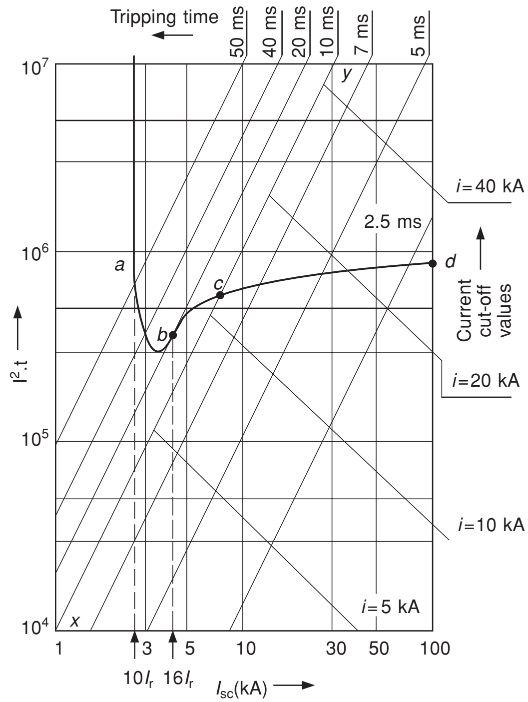
Point b - an arbitrary point showing fault level as 16 *Ir*.
- tripping time – 20 ms.

Point c - illustrates the current limiting threshold
- tripping time limited to 10 ms only.

Zone c–d - illustrates that as the fault current rises the tripping time diminishes relieving the faulty circuit from excessive heating and electro-magnetic stresses.

Point d - represents the breaking capacity of the MCCB.

When required a time delay or an instantaneous trip feature



Note : Below the tripping time curve x–y of 10 ms is the current limiting area.

Figure 13.29(a) Energy based thermal curve for a current-limiting MCCB (Courtesy: Schneider Electric)

can also be introduced in the device. These curves can easily determine the required rating and characteristics of an MCCB at a particular location of the power system. Similar curves can be drawn for electro-mechanical and electronic releases also. While selecting the releases one must ensure that no curve overlaps the other even if the devices are of different brands and characteristics for a discreet discrimination. In electronic releases that are intelligent electronic devices (IEDs) many more features and protections can be incorporated. With the use of telemetry softwares and media they become capable of serial data transmission to monitor and continually improve a process line or a power system from a remote control station (also see Section 13.3.4).

For brevity we limit our discussions only to the selection of protective devices on the basis of energy discrimination. For more details one may see reference 10 under Further Reading.

13.6 Designing a bus system

We discuss in detail in Chapter 28, the procedure to design a bus system, including its mounting and supporting structure and hardware for a required fault level.

13.6.1 Constructional features of a bus system

(i) Busbars and wireways

In the cubicle construction of a switchgear assembly the busbar chamber is normally located at the top of the assembly and runs through the length of it. It is usually suitable for extension, through fish joints at either end, if required at a later date. For installations having top cable entry, the busbar chamber may also be located at the bottom of the assembly or the depth of the panel increased, with an additional shroud between the top busbar chamber and cable chamber. From these main busbars are tapped the vertical buses for each vertical panel. Manufacturers may adopt different practices for horizontal and vertical busbar arrangements to economize on their cost of production. We illustrate the most common types of busbar arrangements.

A separate control wireway may also run through the same busbar chamber, with suitable segregation or shrouding between the main bus and the control bus. This arrangement can be seen in Figures 13.4 and 13.7(a). The control bus system may be required for one or more auxiliary supplies for the following auxiliary services.

1 Motor winding heating up to 30 kW: control bus voltage 24 V a.c.
2 Motor space heaters above 30 kW: control bus voltage generally $\frac{V_r}{\sqrt{3}}$
3 A.C. control supply: control bus voltage generally 110 V or $\frac{V_r}{\sqrt{3}}$

(All values are typical)

Note
The inter-panel control wiring for interlocking between feeders, space heaters and panel illumination will also run through this wireway or control bus chamber.

(ii) Busbar mounting configurations

Manufacturers may adopt different practices to mount the main and auxiliary busbars, depending upon the size, rating and fault level of the system. Some of the recommended and more common of these are illustrated in Figures 13.30(a)–(d) and discussed briefly below.

Arrangement (a)
Busbars are mounted one below the other, horizontally but in a vertical disposition. The cooling is better and requires less derating. The short-circuit withstand capacity is high due to high sectional modulus but occupies more vertical space. This configuration is also adopted by some manufacturers.

Arrangement (b)
This is similar to (a) above but each busbar now is mounted horizontally. Due to obstruction in heat dissipation, this arrangement requires a higher derating. It is also prone to collecting dust and provides a habitable surface for lizards and rodents etc. Therefore this is not a recommended configuration.

Arrangement (c)
This is similar to (a) except that now they are in the same plane and are not one below the other. Although heat dissipation would be slightly better than (b), this too is not a recommended configuration.

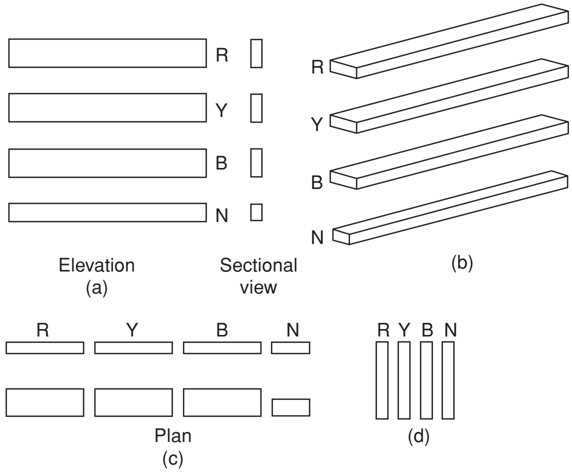


Figure 13.30 Possible arrangements for busbar mounting systems

Arrangement (d)
All busbars are now in one plane and in a vertical disposition and facilitate maximum circulation of air and cooling by natural air currents. This is the most appropriate and most commonly adopted configuration. With such an arrangement any rating is possible. For higher ratings, the Copper Development Association (UK) have recommended many more configurations of busbar arrangements with a view to have a better utilization of the metal up to its optimum capacity. For more details refer to Section 28.7.2(iii) and Figure 28.14.

(iii) Busbar mounting systems

To obtain a strong busbar mounting system, suitable to withstand the electrodynamic forces arising out of a system fault, modern practice is to make use of thermosetting plastics, such as DMC (Dough Moulding Compounds) and SMC (Sheet Moulding Compounds) for the busbar mounting supports. These compounds are suitable for compression, transfer mouldings and injection mouldings. They are basically fibre or glass reinforced thermosetting plastics (FRP or GRP) and possess good physical and thermal stability, high mechanical strength and excellent electrical properties as shown in Table 13.14.

Moulding compounds
With the advent of these compounds in the 1960s, the hitherto more conventional insulating materials, such as phenol formaldehyde (popularly known as Bakelite) and wood (veneered impregnated) have been almost replaced by them. These compounds offer better electromechanical properties than conventional materials. Below we describe the basic mix and properties of these two basic compounds, for a brief reference.

DMC (Dough Moulding Compound)
This is also known as Bulk Moulding Compound (BMC). It is blended through a mix of unsaturated polyester resin, cross linking monomer, catalyst, mineral fillers and short-length fibrous reinforcement materials such as chopped

Table 13.14 Properties of thermosetting plastics

	Properties	*Unit*	*DMC*	*SMC*	*Relevant Standards for test methods*
(I)	**Physical properties**				
	1 Density	gm/cc	1.85–1.95	1.8	BS:2782
	2 Shrinkage	mm/mm	.002–.003	.0015	BS:2782
		%	0.2–0.3	0.15	
	3 Water absorption	%	0.2 (m.)	0.15 (m)	BS:2782
	4 Operating temperature	°C	140–150	140–150	
(II)	**Mechanical properties**				
	1 Minimum tensile strength	kgf/cm^2	250–500	500–900	BS:2782
	2 Minimum compressive strength	kgf/cm^2	1200–1800	1600–2000	BS:2782
	3 Minimum cross-breaking strength or flexural strength (bending strength)	kgf/cm^2	700–1200	1400–1800	BS:2782
	4 Impact strength	kgf cm/cm^2	30–40	60	BS:2782
(III)	**Electrical properties**				
	1 Dielectric strength (min.)	kV/mm	10–14	10–14	BS:2782
	2 Tracking index	V	1000	1000	BS:5901

Note
These values are only indicative and may vary with the quality of mix and process of curing etc., and differ from one manufacturer to another. For exact values, contact the manufacturer.

glass fibre, usually in lengths of 6–25 mm. They are all mixed in different proportions to obtain the required electromechanical properties. The mix is processed and cured for a specific time, under a prescribed pressure and temperature, to obtain the DMC.

SMC (Sheet Moulding Compound)

This is a material produced from the impregnation of glass fibre-mat (fibreglass, which is in the form of dry sheet, is commonly known as chopped stranded mat (CSM)) or rovings, with a liquid and unsaturated polyester resin, which thickens chemically to a dry sheet form. The total mix is sandwiched between polyethylene films and then roller-pressed to impregnate and consolidate it. The chemical thickening enables the material to be handled after the polyethylene film has been removed before moulding.

SMC is used where its superior strength and impact resistance over DMC are more important. The improved properties, particularly its strength, over DMC is a result of reduced degradation of the glass and the ability to use longer fibre. In DMC, this is usually 6–25 mm, while in SMC it is about 25–50 mm.

The compounds so formed have excellent thermal stability and are self-extinguishing and even completely fire-retardant. Their properties are given in Table 13.14. A few common types of insulators and supports are shown in Figure 13.31.

Figure 13.31(a) Insulators to hold busbars in flat configuration (Courtesy: J.K. Plastics)

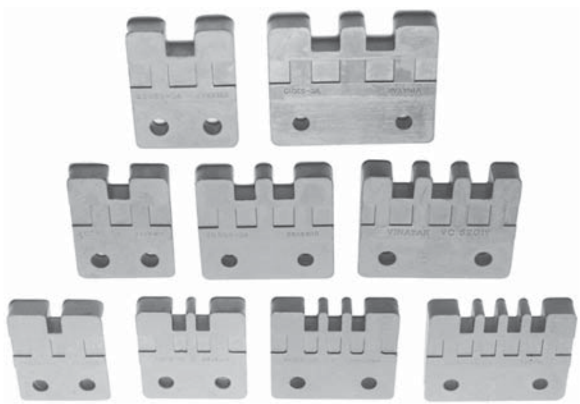


Figure 13.31(b) Insulators to hold busbars in vertical configuration (Courtesy: Vinayak Corp.)

Figure 13.31(c) Conical insulators (Courtesy: J.K. Plastics)

(iv) Making busbar connections

Copper and aluminium are excellent materials for current carrying requirements. Aluminium is preferred due to its low weight and cost advantage. Aluminium, being a highly oxidizing and malleable metal, requires utmost precautions when making a connection or a joint. The joint may be a fish joint for connecting two straight sections of a bus, tap-offs or even the thimbling of cables on the aluminium extended links. To avoid a rapid formation of non-conducting oxide film on the surface of the metal, the surface must be treated properly before making the joint. To avoid this one may take the following precautions:

1 Clean the surface with a wire brush to loosen the oxide film and then wipe it off with a soft cloth. The use of a wire brush serves a dual purpose; first, scraping and removing the oxide film, and second, providing the surface with a moderate knurling (roughness), which helps to make a better surface-to-surface contact and, in turn, a better joint.
2 Apply a contact grease with the following properties:
   - To be chemically neutral
   - To have a nil or negligible electrical resistance and
   - To have a minimum tracking temperature (at which the grease may start conducting) of 200°C. Apply this grease swiftly after the surface cleaning to avoid a fresh oxidation. The following are a few types of greases:
   (a) Servogem 2 (multi-purpose) from the Indian Oil Corporation
   (b) Multi-purpose grease *H* from Hindustan Petroleum Ltd or
   (c) Any other chemically neutral grease, which will have no electrical resistance and which can withstand a minimum tracking temperature of 200°C.
3 The joints must be tightened with a torque wrench. For the recommended torque values refer to Table 29.1.

Note
The minimum tracking temperature is recommended to be 200°C, the same as for the busbars during a fault. (Also see Section 28.4.1). Petroleum jelly is usually not recommended due to its low tracking temperature. But since temperature of 200°C is never reached during normal operation and rarely even during fault, it is a usual practice to use petroleum jelly, being easily available, as a good substitute to grease.

Fasteners

Preferably high tensile (HT) fasteners must be used for busbar jointing and their inter-connections or links not only to take care of the fault level but to also maintain the recommended contact pressure over a long period of operation as noted in Table 29.1. An ordinary fastener may not be able to withstand or sustain this torque for long. Use of Belliville conical washers (Table 29.2) can help in making good joints.

Similarly, the busbar supports, which are mounted on only two or three fasteners, may also be fitted with these fasteners. This however is not essential when more than one busbar is being used and number of fasteners are also more, sharing the electrodynamic forces on fault.

Electroplating of HT fasteners

HT fasteners in normal manufacturing are black phosphated and then lubricated. They are not required to be electroplated, as they do not rust unless the phosphate coat itself is damaged. Such fasteners when used for electrical purposes, such as for mounting and jointing of busbars and their supports, are not generally exposed to outdoor conditions. The phosphate coating thus remains intact and an electroplating (zinc or tin passivation) is not required.

Moreover, electroplating of HT fasteners may pose the problem of hydrogen embrittlement, which can cause cracks on their surfaces. The HT fasteners are already heat-treated and have a high content of carbon. When they are electroplated, whatever hydrogen they may emit during acid pickling is trapped on the surface, as it forms a strong bonding with the carbon. The C–H bonding renders the surface brittle. Rapid removal of hydrogen therefore becomes essential to save the hardware from surface cracks. It is possible to do this by tempering the hardware at a low temperature, say, 100–120°C for about 30 minutes, before transferring them to the electroplating bath.

If such fasteners are stove-enamelled (which is normally not done), the trapped hydrogen is removed automatically while being stoved. Since the fasteners are used only for the assembly of switchgear or busbar systems, they are used at room temperature only. Therefore, if they are electroplated, they must be tampered, which is time consuming and adds to the cost of production. Moreover this has no technical advantage. The HT hardware must therefore be used as they are. When it is absolutely necessary to electroplate them, tampering will be essential.

13.6.2 Service conditions

These are the same as discussed in Section 13.4.2. For busbar systems, however, a more elaborate exercise would be necessary in high rating systems, 1600 A and above, due to skin and proximity effects as discussed in Section 28.6.3.

13.6.3 Complying with design parameters

Rated voltage and frequency

The switchgear assembly, its components and the bus system must be designed for the rated voltage and frequency.

Rated insulation level

To comply with the rated insulation level, all the current carrying components forming part of the assembly should have clearances and creepage distances according to their relevant standards whereas busbars and busbar connections must have the distances noted below.

Clearance and creepage distances for air-insulated busbars

The clearances and creepage distances should be maintained as shown in Tables 28.4 and 28.5. These values can be reduced when:

(a) A barrier of insulation is provided between the conducting parts, such that the clearances and creepages now achieved are no less than as specified in Tables 28.4 and 28.5.
(b) The current-carrying conductors are covered with an insulation suitable for withstanding a one-minute power frequency voltage as in Table 13.2 for series I, Tables 14.1 and 14.2 for series II and Tables 14.3, 14.3(a) and (b) common for series I and II voltage systems.
(c) Any provision or arrangement that can withstand the one-minute power frequency voltage as in these tables at a lesser clearance or creepage distances than specified in Tables 28.4 and 28.5, such as by providing extra insulation wherever necessary. To obtain clearances for open-type outdoor and neutral grounding switchgears, refer to BS 7354.

13.7 Designing LV switchgear assemblies

13.7.1 Rated continuous current rating and permissible temperature rise

The rating of current-carrying devices and components should be selected according to the continuous current they have to carry and the duty they have to perform. Deratings, depending upon the service conditions, should also be applied when deciding their continuous current rating. The sizes selected must then be counter checked for their mechanical endurance to sustain the fault conditions (F_m) of the system or the circuits on which they are connected, depending upon the protective scheme adopted and its time of isolation on fault (i.e. 1 s, 3 s or current limiting) as discussed earlier.

The ratings and sizes of main components and cables can be selected from manufacturers' catalogues. But cables required for the switchgear internal control and power wirings, being typical of all, are normally identified by their cross-sectional area rather than the current ratings because of heavy in-rush currents during closing of contactor or breaker coils, high panel inside temperature and generally high deratings due to many control cables bunched together. We have therefore provided in Table 13.15 the technical data and current ratings for the most common sizes of such cables for a ready reference.

13.7.2 I Design considerations for switchgear assemblies

Below we discuss briefly the constructional requirements and general manufacturing practices for cubicle-type switchgear and controlgear assemblies, and the electrical and the mechanical design considerations to comply with the above design parameters and service conditions.

Table 13.15 Current ratings and technical data for 1100 V, single-core flexible, PVC insulated copper conductor cables for control and power wiring

Cross-sectional area mm^2	*Equivalent diameter of copper conductors* mm	*Nominal thickness of insulation* mm	*Nominal overall diameter* mm	*Maximum resistance at 20°C* Ω/km	*Current rating d.c. or single phase a.c. at 30°C ambient* A
0.5	0.94	0.6	2.3	37.10	4
0.75	1.20	0.6	2.55	24.70	7
1.0	1.34	0.6	2.70	18.50	11
1.5	1.605	0.6	2.95	12.70	14
2.5	2.1	0.7	3.65	7.60	19
4.0	2.61	0.8	4.35	4.71	26
6.0	3.2	0.8	5.65	3.10	46
10.0	4.6	1.0	7.15	1.884	64
16.0	5.9	1.4	8.95	1.138	85
25.0	7.6	1.4	10.65	0.6845	112
35.0	8.7	1.4	11.75	0.5227	138
50.0	10.6	1.6	14.05	0.3538	172

See IEC 60811
Courtesy: Finolex Cables Ltd.
Notes
1 Consider an average derating of 0.67 for power cables when operating at an ambient temperature of 50°C.
2 Consider an average derating of 0.8 for a number of power cables bunched together, generally not more than six at a time.
3 For control cables, derating may not be material in view of very low control currents. Whenever required, the following average deratings may be considered

up to	10	cables	0.70
	20	cables	0.60
	30	cables	0.50
	40	cables	0.40

Constructional requirements and general manufacturing practices

Thickness of sheet steel

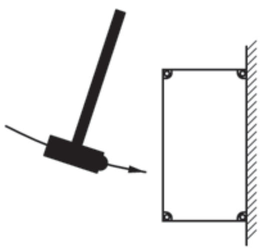
- **Load-bearing members and frame** Two to three mm (14, 12 or 10 BG (British Gauge)) depending upon the size of structure and weight of the components to be mounted.
- **Covers and partitions** From 1.6 to 2 mm (16 or 14 BG). Larger size of doors, doors having a number of relays, instruments and other devices, also doors for mimic control panels etc., required to be mounted with a number of instruments, relays or indicating devices and carrying their load and wiring weight, should be made of thicker gauges and/or stiffeners be provided at the back of the door for strength and to avoid shaking and buckling of doors.
- **Protection against mechanical impacts IK** According to IEC 62262/EN 50102 the equipment enclosures are required to be classified in accordance with their response to impact energy. The enclosures are classified in 11 categories and are designated by Code IK followed by a number. The impact value in joules corresponding to various IK Codes are indicated in Table 13.16. The higher the value of IK Code, the higher will be the ability of the equipment to withstand mechanical impacts from external forces.
- **Base frame** Three to four mm (10 to 8 BG) MS sheet or MS channel of section ISMC-75 (75 mm wide) or ISMC-100 (100 mm wide) depending upon the size and weight of the assembly as shown in Figures 13.48(a) and (b).
- **Gland plate** Three to four mm of MS or non-magnetic material, depending upon the number, sizes and type of cables (single core or multi-core) it has to carry (Figure 13.33).

Note
All the three phases (*R*, *Y* and *B*) of a single-core or a multi-core cable must pass through a common opening in the gland plate. When this is not possible, such as when using single-core power cables, and each core is required to pass through a separate gland to hold it securely in place, the gland plates, through which these cables will pass, must be made of a non-magnetic material (aluminium, SMC/DMC or Bakelite etc). This is an important requirement to eliminate electromagnetic induction in all surfaces that have magnetic properties due to the proximity effect (Section 28.8) caused by each phase. In a three-core cable, the field induced by each phase, being in a circular form, is neutralized, due to phase transposition (Section 28.8.4). In individual single core cables each core produces its own field, which is not neutralized and creates magnetic currents, causing eddy current and hysteresis losses in the gland plate if it is made of MS. This may cause excessive heat in the gland plate and result in insulation failure of the cables. It may also lead to a short-circuit condition.

Corollary
It would be interesting to note that to eliminate such a phenomenon in large metal-enclosed current-carrying systems a segregated phase bus system is in fact preferred, to shield the magnetic influence of one phase on the other (Section 28.2.2). In a segregated system the conductor of each phase is enclosed by metallic barriers, similar to the cable by the gland plate. But a gland plate presents a totally different condition than a segregated system. The thickness of gland plate of only 3–4 mm, provides no shielding for the field produced by each core of cable running through the gland plate. In a segregated system, the enclosure runs the full length of the conductors and provides total shielding for the induced fields. Although the rating of cables may not be high for the purpose of the proximity effect, the close vicinity of its phases, when not in a circular form, may cause enough mutual induction between them, which can heat the gland plate beyond safe limits. MS plates have been seen to melt as a result of this effect leading to a severe fault. Hence the necessity for providing the gland plate of a non-magnetic material when single core cables are being used, to eliminate the main heating constituents, hysteresis and eddy current losses. For details on the proximity effect and magnetic shielding, refer to Sections 28.8 and 27.3.

Table 13.16 Degree of protection against mechanical impacts IK

IK Code	*Impact energy*
00	Not protected
01	0.15 Joule
02	0.2 Joule
03	0.35 Joule
04	0.5 Joule
05	0.7 Joule
06	1 Joule
07	2 Joule
08	5 Joule
09	10 Joule
10	20 Joule



As per Euro norm EN 50102

Other requirements

1. Provision of a segregation between the adjacent feeders in a modular design.
2. Wherever a circuit breaker is to be housed, this should be in a separate compartment.
3. Shrouds and shutters are essential to cover all live parts in a feeder module that may be exposed to the operator when the feeder door is opened (see Figure 13.3). This is a safety requirement for the operator attending the feeder. There may be two types of doors for the accessibility to the live parts:
   (a) Doors which may not be opened for carrying out day-to-day operation or maintenance. Such doors may be almost the fixed type, as for a busbar chamber or the rear panels of a front operated assembly. They may be bolted to the frame so that, when required, they can be opened only with the use of prescribed tools. This is a safety requirement for access to the live parts only by authorized persons. To provide an extra shroud between the door and the live buses/parts in such cases is not mandatory.
   (b) Doors which may be opened often to carry out day-to-day operation and maintenance. They should be the removable type and opened manually. In these cases, all parts that may still be live, even after the switching device has been turned OFF, must be provided with a shroud or a shutter (this is a mandatory requirement as discussed later under interlocking schemes). Refer to Figure 13.3 showing such an arrangement.

   Note
   For instrument modules, relay and control modules or control panels or all power modules, where an interlock

with the door is not possible or is not provided, a proper shroud or shutter must be provided on all exposed live parts rated above 240 V.

4 To provide a folded and extensible construction to allow for ease of alteration and extension of assemblies at site in future, if required.
5 To have a modular construction with a wide choice of module sizes for optimum utilization of the usable area in each vertical panel, which is normally 1800 mm as illustrated in Figure 13.32. The general practice is to have the module sizes in the ratio of 1/6 (300 mm), 1/4 (450 mm), 1/3 (600 mm) and 1/2 (900 mm), etc. Some manufacturers, however, supply 1/8 (225 mm) and 1/9 (200 mm) size of modules also when the sizes and number of components for a module are less and can be accommodated in such a small module size. For critical installations, however, such as for a refinery or a petrochemical plant or for the essential services of a power generating station or installations that are humid or are contaminated, it is advisable to have a module size no smaller than 1/6 (300 mm) with a view to providing more space within the feeder to achieve larger clearances between the live parts and to lessen the chances of a fault during normal operation, besides providing extra working space.

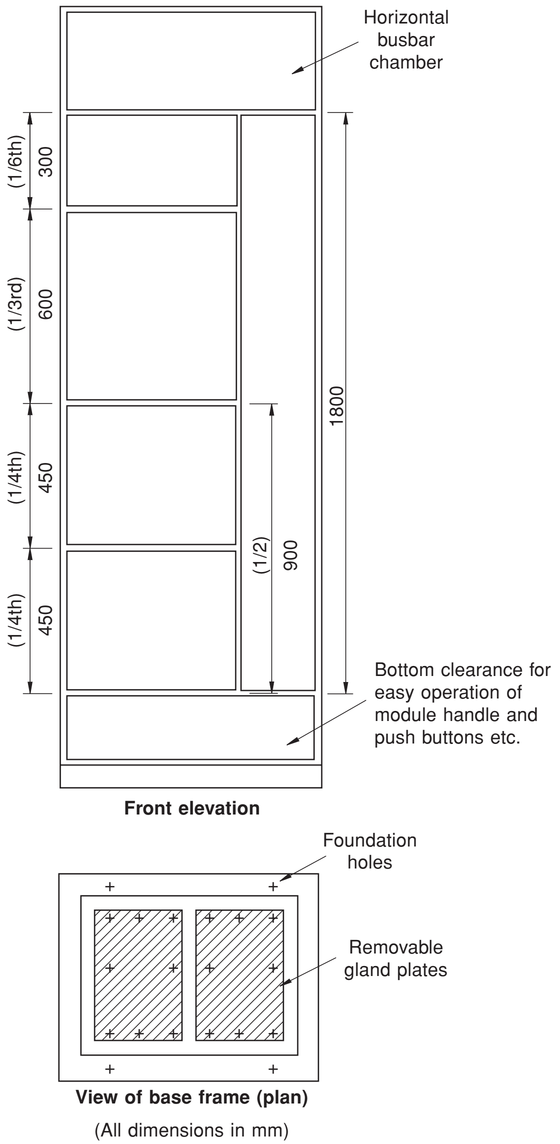


Figure 13.32 Typical module sizes

6 The operating height of each operable mount, i.e. the centreline of the breaker or the switch handle and pushbuttons or reset buttons, including the reset probe of a protective relay on the feeder doors, is recommended to be not higher than 1900 mm from ground level. This is an operational requirement for ease of operation.
7 The height (we may consider it from the bottom line) of the indicating instruments such as a voltmeter and an ammeter, which the operator may have to read often, is also recommended to be not higher than 2000 mm or less than 300 mm from ground level.
8 The terminals provided to receive cables to make external connections, may preferably be located not less than 200 mm (at the terminal centreline) from the gland plate.
9 For ease of maintenance, all the busbars, horizontal or vertical, control or auxiliary, should be easily approachable. Figure 13.34 shows a typical rear view of an assembly with the main horizontal and vertical buses and Figure 13.7(a), illustrates the front of the same assembly with two sets of single-phase control buses.
10 Also the cable alley should be easily accessible to make cable connections, and facilitate easy maintenance and regular checks, as illustrated in Figures 13.7(a) and 13.34.
11 Shrouds are recommended in the front and on the top of the terminals of each feeder to provide protection to the operator from live parts. They will also prevent the tools falling inadvertently from an upper module onto the live terminals of the lower module. Look closely at Figure 13.34 for these features, where in the front is provided a typical translucent shroud to enable a check of the terminals, without opening the shroud. On top is provided another shroud to prevent the terminals from falling tools. If the shroud is of polycarbonate (acrylic has a low temperature index), it should be suitable to withstand a temperature of up to 200°C without deformation. This temperature may be reached during a fault at the terminals.
12 For safety reasons, the busbar chamber and the cable alley should be separate and shrouded from each other.
13 Where wires or conductors may pass through a metal sheet, a rubber grommet, bushing or other mechanical protection should be provided to prevent the wires from insulation damage.

Mechanical interlocks

- Provisions must be made for safety features such as padlocking and door interlocking arrangements. Door interlocking is required to ensure that the feeder door cannot open when the feeder switch is ON.

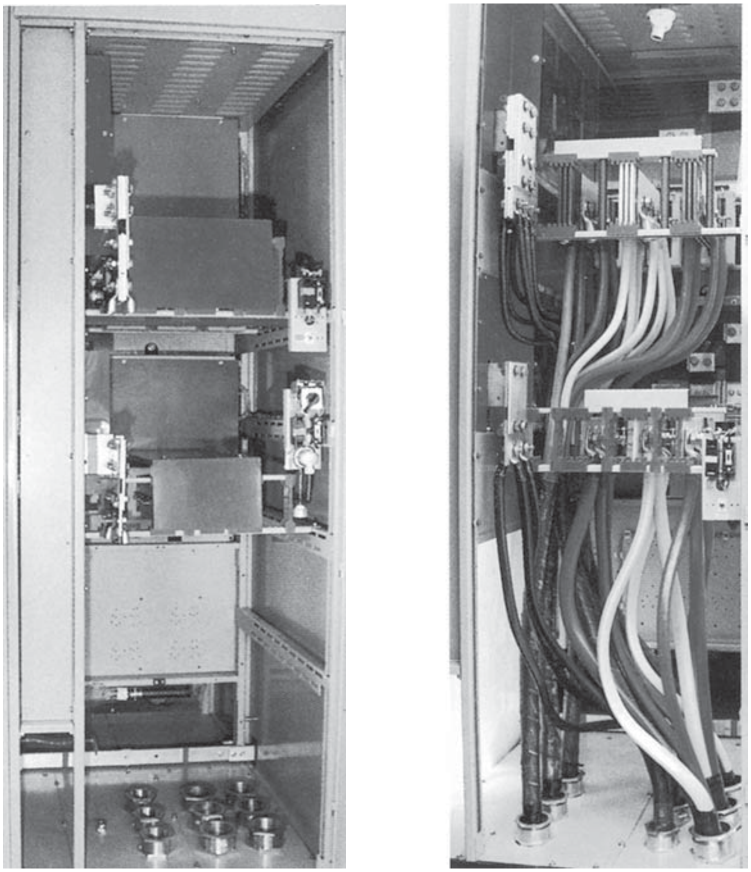


Figure 13.33 Arrangement of gland plates

- Similarly, it must not be possible to switch the feeder ON when feeder door is open.
- A defeat mechanism to bypass the door interlock may also be necessary for the purpose of testing.
- Padlocking arrangements may be required to lock the feeder in the OFF position when the machine is undergoing a shutdown or repairs.

Refer to Figure 13.8(b) showing these features.

Protection from electric shocks (grounding system)

1 ***Main grounding*** The provision of a grounding arrangement is mandatory through the length of the panel. It may be of aluminium, galvanized iron (GI) or copper. (See also Section 22.4.)

2 ***Grounding of each feeder*** The most effective system is to ground each feeder with the main ground bus at one point at least. It is important to note that each feeder is grounded automatically through the metallic supports of the assembly, on which are bolted all the switchgear components (the whole assembly is already grounded). For an ideal condition, an additional grounding of the components should normally not be required but this grounding may not be foolproof due to the painted frame on which the switchgear components are mounted. It is possible that the components may not make a perfect ground contact through the body of the switchgear frame and it is therefore recommended that each component is separately grounded. For a cubicle design, a separate ground bus of a smaller section than the main ground bus may be run through each vertical section and connected to the main ground bus and each individual feeder be bolted through this. Figure 13.35 illustrates this arrangement through one module of a vertical panel.

3 ***Door grounding*** Similarly, the door is also a part of the main frame and is automatically grounded through the mounting hinges and the door closing knobs/latches etc. But a separate door ground wire connecting the frame is also recommended. Where, however, there is no door wiring, no additional door grounding is essential.

Note
For more details on grounding and the grounding practices, refer to Chapters 21 and 22.

13.7.2 II Form of separation

Constructional features in the design of switchgear and

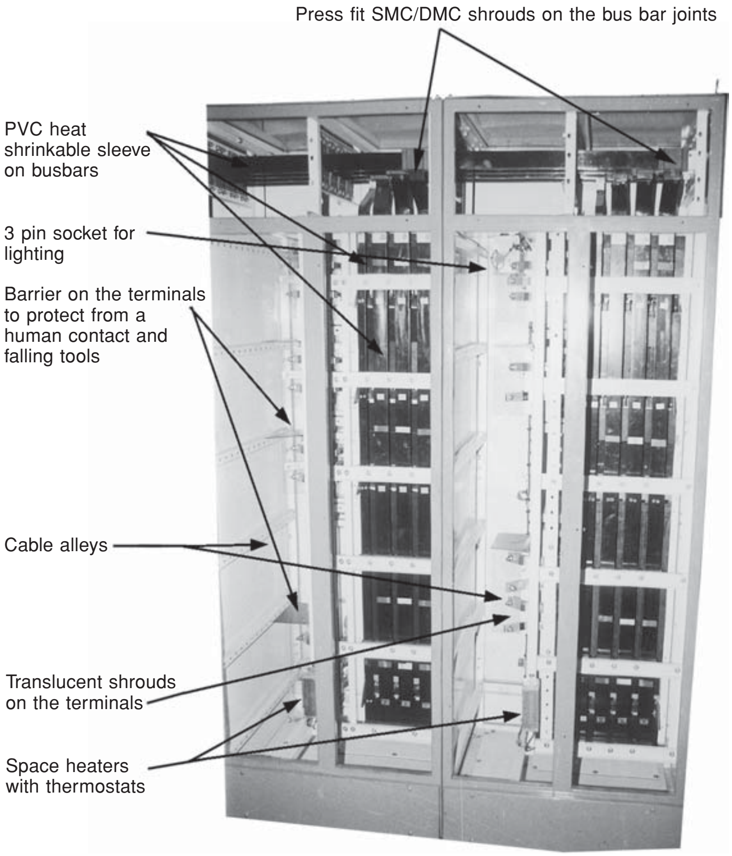


Figure 13.34 Rear view of a typical MCC showing space heaters at the bottom of each cable alley and shrouding of the live parts (Courtesy: ECS) (now Havells India)

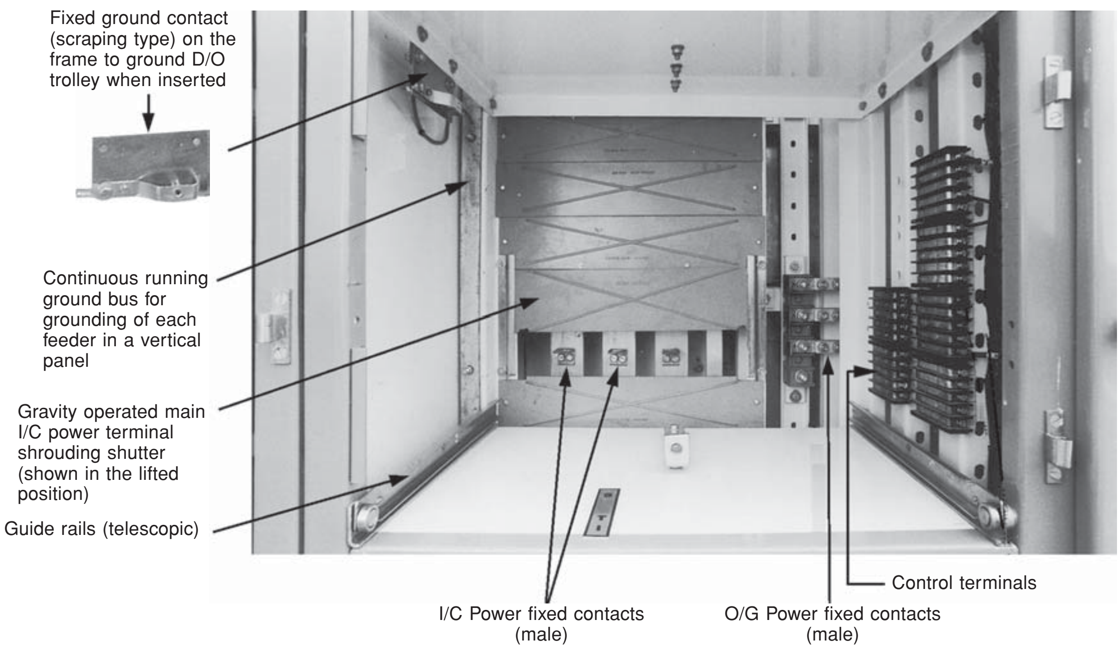


Figure 13.35 View of a module of a fully drawn-out MCC showing grounding arrangement through a continuous running ground bus

controlgear assemblies discussed above relate basically to safety to personnel and maintenance of assemblies. These considerations have now been given greater impetus by IEC 60439-1 identifying these requirements as 'Form of Separation'.

The basic philosophy of this requirement is two fold, one to separate operating personnel from live parts and two, to separate different groups of live parts from each other. Besides safety the separations also provide the following benefits,

- Better opportunity for cable termination in case of live equipment
- Possibility of undertaking emergency repairs in one section of the equipment when another section is live without sacrificing safety
- Limiting propagation of internal arc and arc products and thereby limiting damage
- Preventing passage of solid bodies across the compartments

Form of separation is broadly classified in four forms of separations. Each switchgear assembly basically contains three elements, busbars, functional units and cabling/ termination. Form 1 separation being the most basic and progressively it becomes more stringent. These forms are,

- ***Form 1*** Assemblies do not have an internal separation between these elements.
- ***Form 2*** Assemblies have additional separation of the busbars from the functional units.
- ***Form 3*** Assemblies have additional separation between different functional unit.
- ***Form 4*** Assemblies have additional separation of incoming and outgoing terminals from the busbars as well as from each other.

While Form 1 separation is the least expensive and may appear to be adequate, as it protects against contact with live parts, but in reality there are practical situations when it becomes necessary to work when a section is live. It must be noted that the basic choice lies in selecting between Form 3 and Form 4 separation as Form 2 separation has limited advantage from the consideration of safe working. Form 4 separation permits greatest flexibility permitting connection or disconnection of the external circuits without the necessity of adjacent equipment to be isolated. These basic form of separations are further sub-divided into many forms to closely identify the kind of installation and skill of the operating and maintenance personnel, other protections and safety necessities, if any. And then define the kind of separation that would be essential to meet such necessities, such as separation between different feeder modules, between modules and busbar chamber, between modules and cable chamber and terminals etc. For details refer to IEC 60439-1. To ensure compliance by the manufacturer of the safety requirements the user must specify the type of separation while ordering.

Caution: Provision of any form of separation does not guarantee an operator or the personnel total safety, unless all necessary precautions are taken care of before undertaking maintenance or repair of switchgear assembly.

13.7.2 III Protection from internal arc

From safety point of view this phenomenon too has been given a special consideration for HV switchgear assemblies in IEC 62271-200 and forms one of the test requirements subject to agreement between user and the manufacturer. It mentions that it is not a type test or compulsory test, rather a special test and shall be governed by an agreement between manufacturer and user. Although IEC 60439-1 on LV switchgear assemblies does not specify this test, application guide IEC 61641 (TR) prescribes it for LV switchgear assemblies also. Gradually however, it may form a special test requirement for LV switchgear assemblies similar to HV switchgear assemblies.

The common causes of arc, besides during contact making, interrupting a live healthy circuit or a fault (which are expected to be occurring inside a properly designed switchgear device) can be attributed to the following,

- Insulation failure due to over-heating, ageing, pollution or presence of foreign matters like soot, dust, dirt and moisture condensation etc.
- Similar situation may also occur when a switchgear assembly is energised after a long shutdown without taking due precautions.
- Human error such as use of wrong component or omission of fitting shrouds, arc chutes or barriers while replacing the components.
- Component failure as a result of overheating due to poor joints or ageing.
- There may also be regular luminous discharges or tracking across the insulating material leading to severe arcing or puncture of insulating materials.

Internal arc results in building-up of internal pressure and temperature and depending upon its severity can result in forced opening of doors or flying of inside components and that can be dangerous for the personnel and equipment nearby.

The arcing on fault and consequent build-up of inside pressure cannot be avoided, but its severity can be contained by preventing its propagation through adequate constructional safety measures such as barriers, shrouds and separations as noted in the previous section and clearing the fault quickly by adequate electrical protections. A pressure relief mechanism in switchgear assembly to allow the hot ionized gases escape may also be advisable to avoid explosion due to inside pressure.

13.7.3 Essential features of a draw-out MCC

1 All power and controlgears are mounted on withdrawable chassis (Figure 13.36).
2 The chassis moves on low-friction rolling mounts or guide rails (Figures 13.7(a) and (b) and 13.36).
3 Guide rails are telescopic and are necessary to ensure safe and aligned movement of the trolley while racking it in or out of its module to avoid misalignment of the moving contacts. A misalignment may cause an inadvertent contact of the draw-out contacts with the

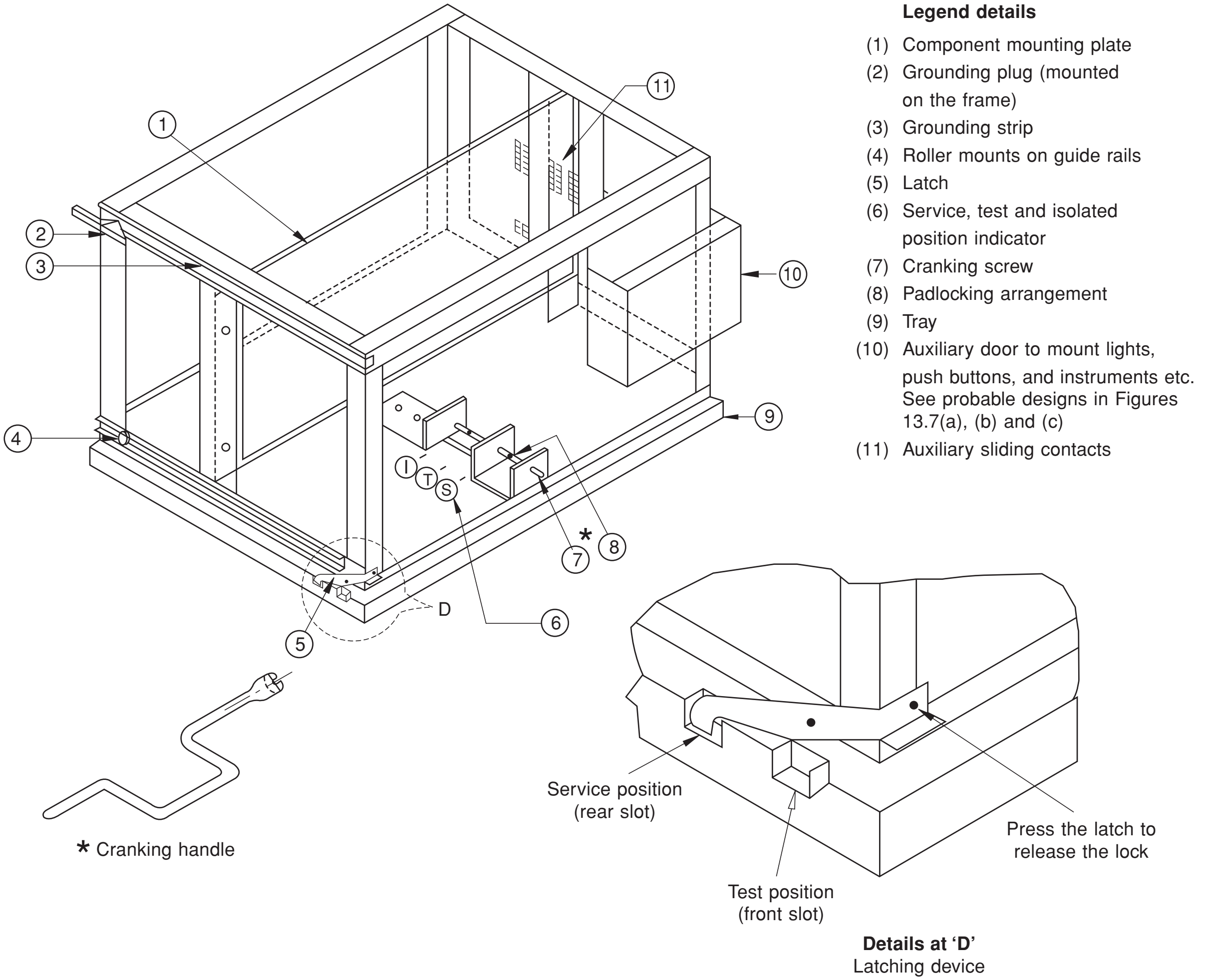


Figure 13.36 Front view of a typical withdrawable chassis (trolley)

adjacent fixed contacts of the other phases, which are mounted on the live vertical bus (Figure 13.35) and may cause a flashover and a short-circuit.

4 The chassis for both fully draw-out and semi-draw-out MCCs is fitted with self-aligning plug-in-type high-pressure contacts for incoming and outgoing power connections. The control terminals for control connections are the manually connected, plug-in type in semi-draw-out-type MCC, as shown in Figure 13.6(a) and spring-loaded sliding-type in a fully draw-out MCC, as shown in Figures 13.6(b) and (c).

5 It is preferable to provide a cranking or a push-in device with a latching arrangement to lock the trolley in both service and isolated positions, as shown in Figure 13.36.

6 For a positive ground connection and to provide total safety for the operator, a spring-loaded scraping type grounding assembly may be provided on each trolley so that the moving part can slide on the fixed grounding strip fitted in the assembly, and make before and break after the power contacts have engaged or disengaged respectively. Figures 13.7(a) and 13.35 illustrate such an arrangement. The grounding contact may be of brass and silver plated (a good practice). It may be fitted on the tray of each module and permanently connected to the ground bus running vertically through each vertical panel and connected to the main horizontal ground bus.

A positive grounding arrangement will mean automatic grounding of the trolley as soon as it is mounted on the tray for racking-in and then remaining in permanent contact with the ground contact when the trolley is fully racked into its service position.

7 In a draw-out MCC, it is recommended that shrouds are provided at the main incoming power contacts, from where the vertical bus is tapped, to feed the draw-out module. Manufacturers may adopt different practices to achieve this. The most common is a DMC/SMC (Bakelite, which was more common earlier, is now discarded, being hygroscopic and inflammable) gravity-operated drop-down shutter, which lifts automatically while the trolley is being racked in and slides down as the trolley is being racked out.

Refer to Figure 13.35, showing a feeder with the shroud lifted. Figure 13.7(a) also illustrates a few feeders with shrouds fitted. One of the feeders is also shown with a lifted shroud.

8 Indicating instruments, lamps, pushbuttons, selector switches and reset knobs etc. are mounted on the trolley on a hinged auxiliary door, as shown in Figures 13.7(a) and 13.8(a).

The main outer door on the frame may have either an opening to seat the auxiliary door of the trolley on it as shown in Figure 13.7(c) or telescopic knock-outs for all such door mounts to provide a peep-through type of aperture. On it are mounted the light and pushbutton tops. Figures 13.7(a) and (b) and 13.8(a) illustrate this type of arrangement. The latter alternative provides a better arrangement, for it ensures a greater degree of protection. It has the most significant advantage when the trolley is removed from its module and the outer door can still be securely shut on the module to provide total protection for the empty module from dust, vermin and rodents as well as inadvertent human contact with the live incoming terminals. In the other design, the outer door has a large knock-out to seat the auxiliary door, which may remain open when the trolley is removed for repairs or replacement, and expose the interiors.

9 Low contact resistance is desirable at all current-carrying contacts, such as the busbar joints, between busbars and the incoming fixed power contacts, between incoming fixed power contacts and incoming moving power contacts on the trolley and between the outgoing moving and fixed power contacts etc. This is to ensure proper surface-to-surface contact and eliminate arcing between them. Otherwise it may develop hot spots and result in corrosion of the contacts in the normal operation. It may also lead to an eventual failure of the joint/contact.

To measure contact resistance: Contact resistance meter can be employed. Periodic monitoring of contact resistance and maintaining a logbook is a good maintenance practice to keep the main and arcing contacts in good condition. A contact resistance meter can measure dynamic resistance in live circuits also.

Note
The main incoming male contacts are generally made of copper or brass and are either bolted or clamped on the vertical bus. Since the bus is generally of aluminium, the contacts may form a bimetallic joint with the busbars and cause corrosion and pitting of the metal. This may result in a failure of the joint in due course. To minimize metal oxidation and bimetallic corrosion, the contacts must be silver plated.

If the main incoming male contacts are made of aluminium alloy, which is normally a composition of aluminium-magnesium and silicon, they must be provided with a coat of bronze, copper and tin to give it an adequate mechanical hardness and resistance to corrosion. For more details refer to Section 29.2.5.

10 Each trolley is recommended to possess three distinct positions of movement, as shown in Figure 13.36, i.e. 'service', 'test' and 'isolation':

Service: this is the position of the trolley when it is fully inserted into its housing (module) and the power and control contacts are fully made.

Test: This is the position of the trolley when the power contacts are isolated but the control circuit is still connected, because it is tapped directly from the auxiliary bus. This condition is essential to facilitate testing of control circuits with functional interlocks, without energizing the connected load.

Isolation: This is the position of the trolley when the power and the control circuits are both isolated. Depending upon the site requirements, sometimes the control circuit may be required to be still energized for some test requirements.

11 The feeder door should not close unless the trolley is racked-in, up to the test position at least.

12 The trolley should not permit its withdrawal when its switch is in the ON position.

13 While racking-out the trolley, it should not be possible to completely withdraw it unless it has reached the 'isolation' position. In the isolation position there must be a 'holding-on' latch arrangement, to prevent an abrupt fall of the trolley from its module. Figure 13.36 illustrates this feature.

14 Interchangeability of a module with another module of the same type and size is the basic requirement of such panels.

15 Provision of an extra interlocking facility (peg and hole system) may also be essential to prevent interchangeability between two similar trolleys when the circuits or the functions of the two otherwise identical trolleys are different, and it is undesirable to interchange these trolleys.

16 Withdrawal of a draw-out circuit breaker or a withdrawable switch or contactor will not be possible unless they are in an OFF position.

17 Operation of withdrawable equipment, such as a breaker or components on a withdrawable chassis, will not be possible unless it is in service, test, isolated or totally removed positions.

13.7.4 Requirements other than constructional features (applicable on all types of switchgear assemblies)

1 Mechanical and electrical interlocks

- An industrial load having a connected load requirement of more than 2000 kVA may normally call for more than one feeding transformer for limiting the fault level of the system, as discussed in Section 13.4.1(5). It may also have a standby emergency source of supply. The two feeding transformers, although they may be identical electrically and suitable for parallel operation, are not supposed to run in parallel with a view to limiting the fault level. The emergency source, as a result of different electrical parameters, is not run in parallel with any of the two incoming sources. To achieve the required safety by avoiding a parallel operation, it is essential to provide a mechanical or an electrical interlock or both between all the incoming feeders. Schemes to achieve the required safety interlocks are described in Section 13.7.5.

- When there are more than one sources of supply, it is recommended to distribute the loads also in as many sections as the incomers, and provide a tie-circuit between every two sections, to obtain more flexibility. Now fault on one section or source of supply will not result in the loss of power to the entire system. Figures 13.16 and 13.17 illustrate this type of distribution.

2 Potential/control transformers must be provided with current limiting fuses at both ends.

3 **Control wiring** Wiring from supervisory or annunciator devices to the terminal blocks may be carried out with thinner wires, as may be recommended for such devices. However, they should run through separate wire bunches, and not through the bunches of control wires for easy identification and to remain unaffected by heat of control wires.

4 For easy identification and prompt maintenance it is mandatory to segregate all control wires when they are carrying more than one control supply (e.g. at different voltages both a.c. and d.c.), and run them in separate bunches. The control wires must also be of different colours for different control supplies. The colour codes have been standardized for different control supplies (refer to IEC 60445).

5 **Space heaters with temperature control** These are recommended with a view to eliminate condensation of moisture, particularly when the switchgear is idle and the atmosphere is humid. The space heaters are normally rated for $V_r/\sqrt{3}$, 40W, single phase. They are located appropriately such as in the cable alley, and are switched ON when the switchgear is likely to be idle for a long period. The number of space heaters will depend upon the size and type of the switchgear assembly. For a cubicle-type panel, it is recommended that at least one space heater be provided in each vertical panel. They should be mounted at the lower portion of the panel for better heat circulation through natural heat convection.

Figure 13.34 illustrates a likely location for such a heater. To prevent condensation of moisture they are recommended to reach a temperature rise of only 5–10°C above the ambient temperature, inside the housing and are controlled automatically through a pre-set thermostat.

6 A three-pin socket, rated for $V_r/\sqrt{3}$, 5 A, may also be provided for panel lighting or hand lamp (Figure 13.34).

7 Panel numbering on acrylic sheet or aluminium anodized plates may be fixed on the front and the rear of each vertical panel for quick identification of each panel section (Figure 13.9(a)).

8 For safety to personnel during maintenance and to protect the live system from lizards and rodents the busbars may be covered with PVC tape or heat shrinkable PVC sleeve. The joints and the tap-offs can be protected through PVC/SMC/DMC/polycarbonate shrouds, as shown in Figures 13.37(a) and (b). The

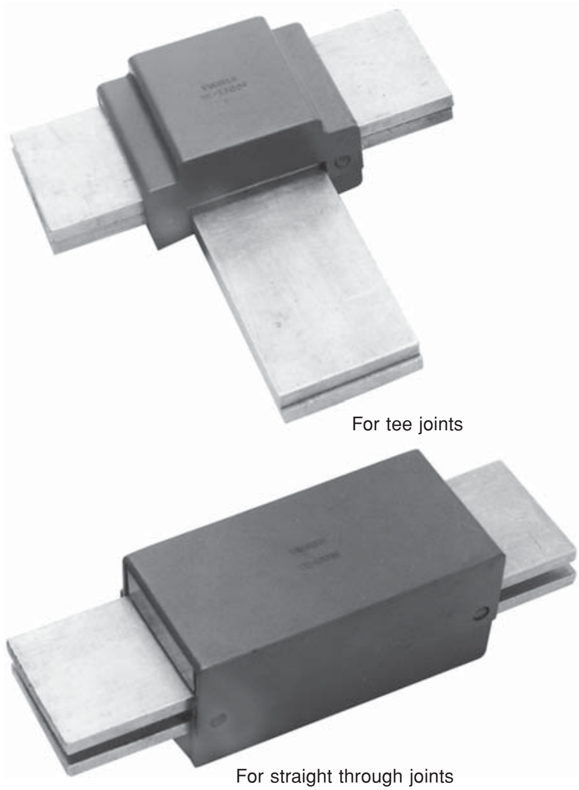


Figure 13.37(a) Pressfit PVC/SMC/DMC/polycarbonate shrouds for busbar joints

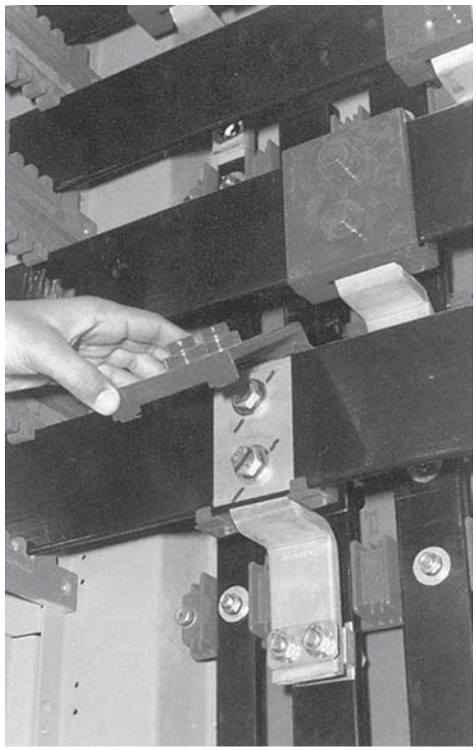


Figure 13.37(b) PVC/SMC/DMC/polycarbonate shrouds for bus joints and tap-offs

PVC taping, however, is not reommended for it may suffer cuts or tear off during working on the busbars and become loose or worn-out with time. PVC sleeving is a more recommended practice but sleeving[a] if not done properly may not provide a true skin-fit through the length of the busbars, and may affect its cooling. At certain places, it may have air pockets from where it will provide a reduced heat dissipation.

For higher rating systems, say 2500 A and above, sleeving is normally not preferred. Instead, a non-metallic, semi-glossy black paint[a] (preferably epoxy) may be provided to make the bus conductors act like a black body and dissipate more heat. This will also add to the current-carrying capacity of the busbar system. Painting black is not a measure of safety but a technique to enhance the current carrying-capacity of the busbar system. For safety during maintenance, some other form of shrouding can be provided, such as by providing PVC/SMC/DMC/polycarbonate shrouds at all such places where the live bus may be exposed to the operator attending to maintenance work. Epoxy coating of links is a good practice.

[a] *Note*
True skin tight black sleeve or matt finish black paint also prevents the metal from oxidation and improves cooling. Oxidation is a thermal insulating film and a hindrance to the natural heat dissipation and may be prevented by these procedures.

9 For precautions in making joints, refer to Section 29.2.
10 Painting. A thorough surface treatment of the sheet metal and a good painted surface are prerequisites for the switchgear and control gear assemblies to provide long years of rust and corrosion free operation. For the benefit of those in the field of manufacturing of such assemblies, we have provided a brief procedure for the sheet treatment, surface painting and effluent treatment in the Appendix A-13.

The above are the more obvious constructional, design and safety features for a switchgear or a controlgear assembly. For more details and additional requirements refer to IEC 60439-1 for LV, IEC 62271-200 and IEC 60694 for HV and ANSI-C-37/20C, common for LV and HV switchgear and controlgear assemblies.

13.7.5 Interlocking of feeders to prevent parallel operation

Mechanical interlocking schemes

Use of castle locks

Different figure locks such as A –, – B and AB are used with a common master key (Figure 13.38). The master key can unlock all locks A –, – B or AB because it has grooves for both A and B but will be locked with the lock that it unlocks. To remove the key, the lock must be locked first. Then only the key can be used for the other locks and thus achieve the required interlocking. The lock holds the lever of the closing mechanism of the interrupter and prevents it from closing. Lock AB can be unlocked by either of the keys A – or – B. The number of locks will be the same as the number of interrupting devices, but the keys will be less and will be for only as many interrupting devices as are permitted to be switched at a time (generally equal to the number of supply sources).

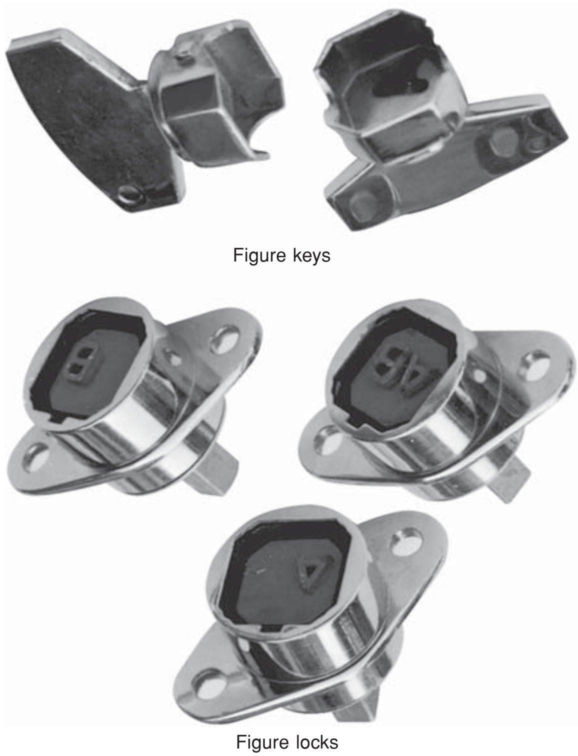


Figure 13.38 Castle figure locks and keys

Two sources of supplies (Figure 13.39)

The two incomers (I/C), fed from two different sources, can be fitted with two locks A – and – B, and one master key AB. This key will allow only one incomer to be switched at a time.

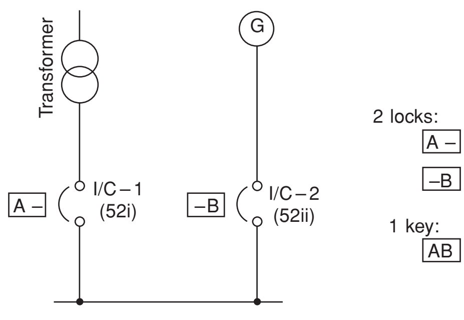


Figure 13.39 Two sources of supply

Two sources of supplies and a bus coupler (Figure 13.40)

The two incomers (I/C) and the coupler can be fitted with three locks, | A – |, | – B | and | AB | and two keys | A – | and | – B |: locks | A – | and | – B | for the incomers and | AB | for the coupler. The key | A – | can operate I/C-1 or the coupler and key | – B | can operate I/C-2 or the coupler. Thus, only two of the three interrupting devices, I/C-1 and coupler, I/C-2 and coupler, or I/C-1 and I/C-2 can be switched at a time to achieve the required interlocking.

Three sources of supplies and two bus couplers (Figure 13.41)

The three incomers and two couplers can be fitted with five locks, | A – |, | – B |, | C – |. | AB | and | CB | and three keys | A – |, | – B |, and | C – |.

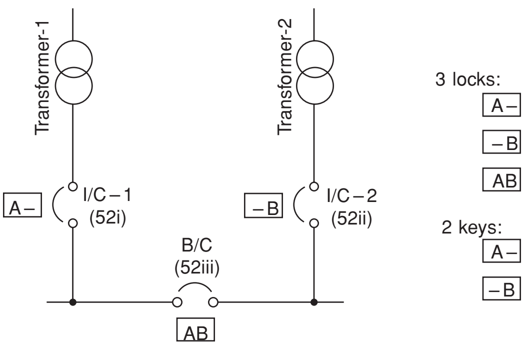


Figure 13.40 Two sources of supply and a bus coupler

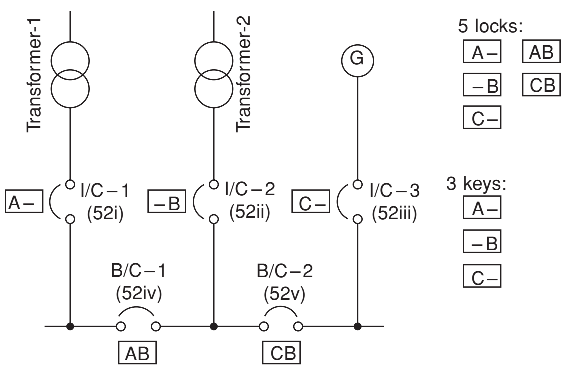


Figure 13.41 Three sources of supply and two bus couplers (Figures 13.39–13.41 are mechanical interlocking schemes)

The interlocking is achieved as follows:

Key | A – | – can allow switching of I/C-1 or coupler 1

| – B | – can allow switching of I/C-2, coupler 1 or coupler 2

and | C – | – can allow switching of I/C-3 or coupler 2

Thus, only three of the five interrupting devices can be switched at a time as required without causing a parallel operation between any of the two incomers.

For a larger number of supply sources, each having two interrupting devices, one as incomer and the other as coupler, two more locks, i.e. | – D | and | CD | and one key, i.e. | – D | may be added for each extra source and so on.

Note

The mechanical interlocking scheme is generally required for manually operated interrupting devices not fitted with electrically operated tripping mechanisms such as an under-voltage (U/V) or a shunt trip (S/T) release. A switch or a switch fuse unit (SFU or FSU) is a device that cannot be provided with an electrically operated tripping mechanism. Sometimes even manually operated breakers or MCCBs which can be fitted with an U/V or S/T are required to have a mechanical interlocking scheme, although this is not a preferred method when an electrical interlocking scheme is possible. This aspect is discussed later.

When the breaker (including an MCCB) is provided with an electrical closing mechanism through a motor or a solenoid, mechanical interlocking is not recommended as mechanical interlocking will make electrical closing redundant.

Electrical interlocking schemes (when the interrupters are manually operated)

The preferred way to achieve interlocking between more than one source of supplies is through electrical schemes only, wherever possible. They are foolproof and can also be operated remotely. Mechanical schemes are generally for smaller installations where, as a result of smaller ratings or cost considerations, a breaker is not used and that imposes a limitation on adopting an electrical interlocking scheme.

The electrical interlocking should preferably be provided through shunt trip releases. It must have a separate a.c. or d.c. source of control supply, such that the operation of the scheme is independent of the main source of supply. For the same reason, interlocking through under-voltage (U/V) releases is not recommended as its operation would be dependent on the condition of supply. An U/V release is generally fitted to trip the interrupting device when the supply ceases and not for any other control scheme.

The schemes are logical and simple and have been drawn, to ensure that no two supply sources can ever be switched in parallel. The scheme prevents to switch an interrupter, that may cause it to operate in parallel with another, unless the first source is opened first. This is illustrated in the following schemes.

Two sources of supplies (Figure 13.42)

The NO (normally open) contact of I/C-1 (52i) is wired in the trip circuit of I/C-2 (52 ii) and vice versa. As soon as an interrupter is closed, the tripping circuit of the other gets ready to trip.

Note
The function of a shunt trip coil is to trip an interrupter. As soon as its coil is energized, it releases the closing lever of the interrupter and trips it. The coil is rated for a short-time, since it is in the circuit for a very short-period only when it is required to trip the interrupter. To ensure that it does not continue to remain energized after carrying out its function, the interrupter's 'NO' contacts are also wired in series with the coil as shown. The coil becomes de-energized as soon as the interrupter trips. Normally two NO contacts of the interrupter are wired in series, as standard practice, by the interrupter (breaker or MCCB) manufacturers to share the arc energy on a trip and enhance contact life, particularly when the control supply is d.c. which normally is the case.

Two sources of supplies and a bus coupler (Figure 13.43)

The logic is the same as above. In the trip circuit of each interrupter is wired the NO contacts of the other two interrupters. Obviously only two of the three interrupters can be switched at a time.

Three sources of supplies and two bus couplers (Figure 13.44)

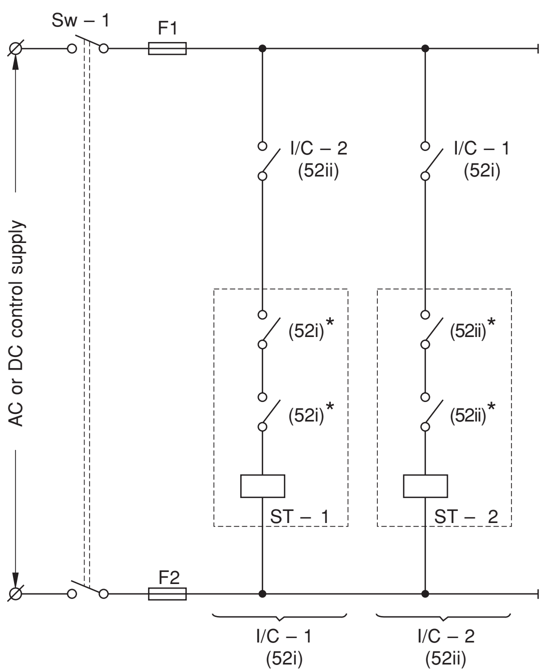
The scheme is now more complicated but the following logical approach will make it simple:

(a) When I/C-1 (52i) is required to be switched

(i) Interlocking with I/C-2 (52ii): I/C-2 (52ii) and B/C-1 (52 iv) should not be in a closed position at one time.
(ii) Interlocking with I/C-3 (52iii): I/C-3 (52iii), B/C-1 (52iv) and B/C-2 (52v) should not all be in a closed position at one time. Refer to the control scheme for I/C-1 (52i).

(b) When I/C-2 (52ii) is required to be switched

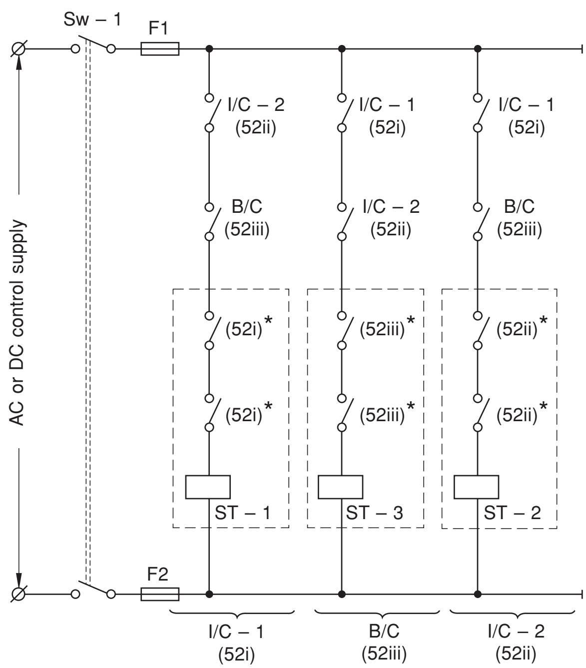
(i) Interlocking with I/C-1 (52i): I/C-1 (52i) and B/C-1 (52iv) should not both be in a closed position at one time.
(ii) Interlocking with I/C-3 (52iii): I/C-3 (52iii) and B/C-2 (52v) should not both be in a closed position at one time. Refer to the control scheme for I/C-2 (52ii).



Legends details
Sw – 1 – Control supply ON/OFF switch
$F_1 – F_2$ – Control fuses
ST_1, ST_2 – Shunt trip coils of breakers
I/C – 1, 2 or 52(i, ii) – Incoming sources of supplies

*Note Normally 2NOs of the interrupters are wired in series to share the arc energy and enhance the contact life.

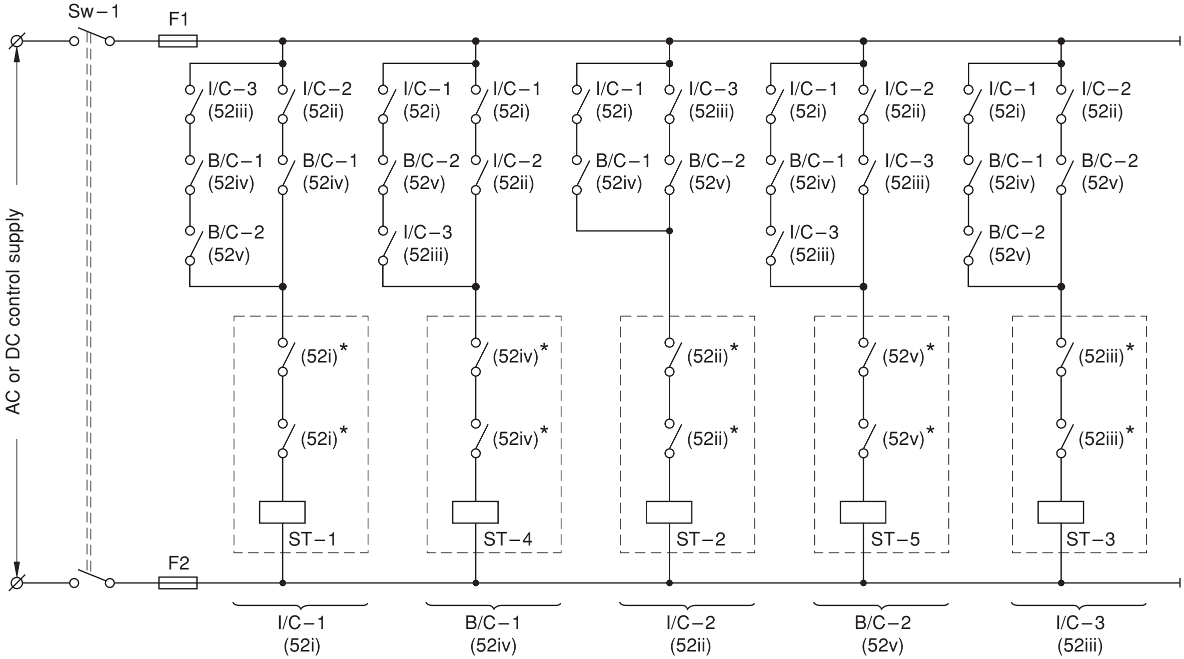
Figure 13.42 Electrical interlocking scheme for manually operated breakers for two sources of supplies



Legends details
Sw – 1 – Control supply ON/OFF switch
$F_1 – F_2$ – Control fuses
ST_1, ST_2, ST_3 – Shunt trip coils of breakers
I/C – 1, 2 or 52(i, ii) – Incoming sources of supplies
B/C – 1 or 52(iii) – Bus coupler

*Note Normally 2NOs of the interrupters are wired in series to share the arc energy and enhance the contact life.

Figure 13.43 Electrical interlocking scheme for manually operated breakers for two sources of supplies and a bus coupler



Legends details

Sw – 1	— Control supply ON/OFF switch
$F_1 – F_2$	— Control fuses
ST_1, ST_2, ST_3, ST_4 and ST_5	— Shunt trip coils of breakers
I/C-1,2,3 or 52(i,ii,iii)	— Incoming sources of supplies
B/C-1,2 or 52(iv,v)	— Bus couplers.

**Note* Normally 2NOs of the interrupters are wired in series to share the arc energy and enhance the contact life.

Figure 13.44 Electrical interlocking scheme for manually operated breakers for three sources of supplies and two bus couplers

(c) When I/C-3 (52iii) is required to be switched

(i) Interlocking with I/C-2 (52ii): I/C-2 (52ii) and B/C-2 (52v), should not both be in a closed position at one time.

(ii) Interlocking with I/C-1 (52i): I/C-1 (52i), B/C-1 (52iv) and B/C-2 (52v) should not all be in a closed position at one time. Refer to the control scheme for I/C-3 (52iii).

(d) When B/C-1 (52iv) is required to be switched

(i) Interlocking with I/C-1 (52i) and I/C-2 (52ii): These should not be in a closed position at one time.

(ii) Interlocking with I/C-1 (52i) and I/C–3 (52iii): I/C-1 (52i), B/C-2 (52v) and I/C-3 (52iii) should not all be in a closed position at one time. Refer to the control scheme for B/C-1 (52iv).

(e) When B/C-2 is required to be switched

(i) Interlocking with I/C-2 (52ii) and I/C-3 (52iii): Both should not be in a closed position at one time.

(ii) Interlocking with I/C-1 (52i) and I/C-3 (52iii): I/C-1 (52i), B/C-1 (52iv) and I/C-3 (52iii) should not all be in a closed position at a time. Refer to the control scheme for B/C-2 (52v).

Electrical interlocking schemes when the interrupters are also electrically operated

Motor-operated interrupting devices are employed when the system requires remote-controlled power switching, as for an auto-reclosing scheme. The electrical interlocking schemes remain generally the same, as discussed earlier, but with an additional circuit for the motor spring charging mechanism and the closing coil of the interrupter. Brief details of the electrical closing features are as follows.

Spring charging motor mechanism

The purpose of the motor is to charge the closing spring that closes the interrupter, independently of the speed and operation of the motor or of the operator when closed manually. (The interrupter can be closed manually or electrically when the spring is fully charged.) As soon as the spring is discharged, the motor recharges it automatically to prepare it for the next operation. The motor may be fed through the same source as for the main control scheme or another source, depending upon the system design. But the source must be reliable and independent of the main power supply as far as possible (such as through a battery).

Note
Small interrupters and MCCBs particularly may be electrically operated through a solenoid valve.

Limit switch (LS)

The spring charging mechanism is fitted with a limit switch, having generally 2NO and 2NC change-over contacts. The 2NC contacts are wired in series with the motor to allow it to charge the spring mechanism immediately on discharge of the spring, to prepare it for the next operation. As soon as the spring is fully charged, the NC contacts change over to NO and cut off the supply to the motor terminals (Figure 13.45). The 2NO contacts of the limit switch are wired in series with the closing coil of the interrupter. As soon as the spring is fully charged these contacts change over to NC and the closing coil circuit gets ready to close.

Closing coil (CC)

The charged closing spring may be released manually or electrically by energizing a closing coil as shown in Figure 13.45.

Breaker control switch (CS)

To close or trip the interrupter locally or remotely a breaker control switch is also wired with the closing and the shunt trip coils of the interrupter, as shown in Figure 13.45. The switch is a spring return type to ensure that it resumes its original (neutral) position as soon as it has carried out its job of closing or opening the interrupter. With the above features in mind, the control logic for the various interlocking schemes becomes simple as shown in Figures 13.45–13.47:

- Two sources of supplies: Figure 13.45.
- Two sources of supplies and a bus coupler: Figure 13.46.
- Three sources of supplies and two bus couplers: Figure 13.47.

13.7.6 HV switchgear assemblies

Use of an LV switchgear assembly is more frequent than that of an HV switchgear assembly. Moreover, HV assemblies above 33 kV are generally the outdoor type and installed in the open. The discussions above have therefore laid greater emphasis on the features of an LV switchgear assembly. The features for an HV assembly up to 33 kV are not very different except for thicker enclosure and heavier load-bearing members, to carry larger HV equipment (interrupting devices, CTs, VTs, insulators, etc.). The clearances and creepage distances will also be greater, according to the system voltage (Section 28.5.2). For more details refer to IEC 62271-200, IEC 60694 and ANSI-C-37/20C.

Gas Insulated Switchgear (GIS) Use of GIS up to any voltage has changed the concept of conventional air insulated enclosures. GIS are energy saving, compact, reliable

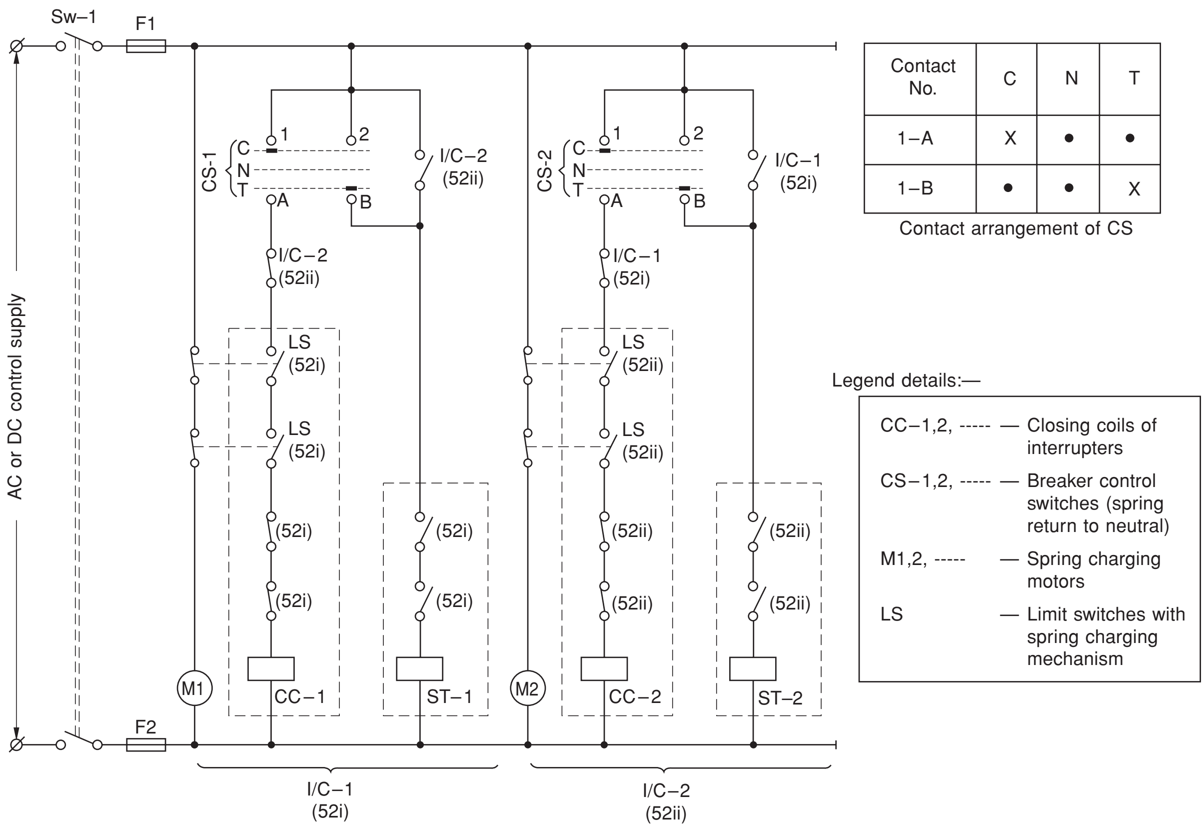


Figure 13.45 Control scheme for two electrically operated breakers and two sources of supplies

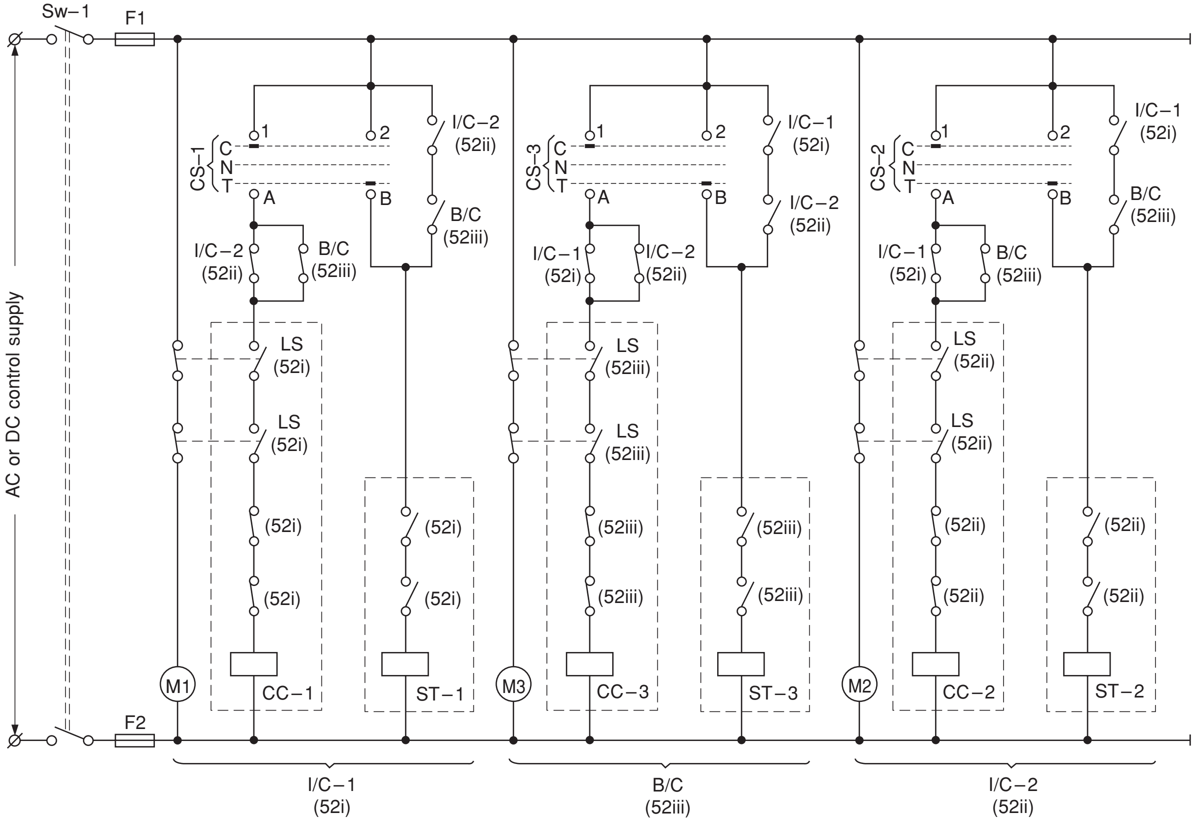


Figure 13.46 Control scheme for two electrically operated breakers, a bus coupler and two sources of supplies

and more safe and can meet all site and system requirements at reasonable cost. For details see Section 19.10.

13.8 Incorporating protection schemes

Protection schemes constitute mandatory feature of a switchgear assembly. Many simple protections like overloads and short-circuits are possible through direct acting thermal releases and fuses alone that usually form a part of the main device that may be a switch, contactor or a breaker. But power systems and equipment demanding for discriminative protection with optimum speed, a more comprehensive and accurate protective scheme becomes essential, calling for a number of protective relays in tandem. These relays measure complex operating conditions like detecting and locating the fault or analyzing the operating conditions to initiate pre-warning commands as a measure to provide an opportunity to the operating personnel, to restore the operating conditions within desirable limits if possible or isolate the faulty section or equipment from the circuit. All such relays form a part of the composite switchgear assemblies. Table 13.17 provides a broad comparison between different kinds of relays available in the market to make a better choice, while Table 13.18 provides the relays and other devices function numbers used commonly as per ANSI Standard for a general reference.

Consider Figure 13.21 showing a general powerhouse generation and transmission layout. For brevity we have restricted our discussion to the protection of the main equipment only such as the generator, unit auxiliary transformers (UATs) and the generator transformer (GT). These three items have been taken out of Figure 13.21 for more clarity and redrawn as Figure 16.14 for generator protection and Figures 13.47 (a) and (b) for protection of UATs and GT respectively. The protection of the remaining system is a matter of system design and appropriate application of the protective devices available in the market depending upon system requirements. Figure 13.47(c) shows a typical feeder protection scheme.

(i) ***Generator protection*** (for protection scheme see Section 16.8, Figure 16.14)

(ii) ***Protection of unit auxiliary transformers (UATs)***

- 49-UT RTD protection for warning of winding overheating (see also Sections 12.7 and 12.8)
- 51-UT Over-current protection
- 51N-UT Ground fault protection
- 63-UT Gas protection through a Bucholtz relay
- 64R-UT Restricted ground fault protection
- 87-UT Differential protection to detect a phase-to-phase fault

(iii) ***Protection of generator transformer (GT)***

- 49-GT RTD protection for warning of winding overheating.

(Contd.)

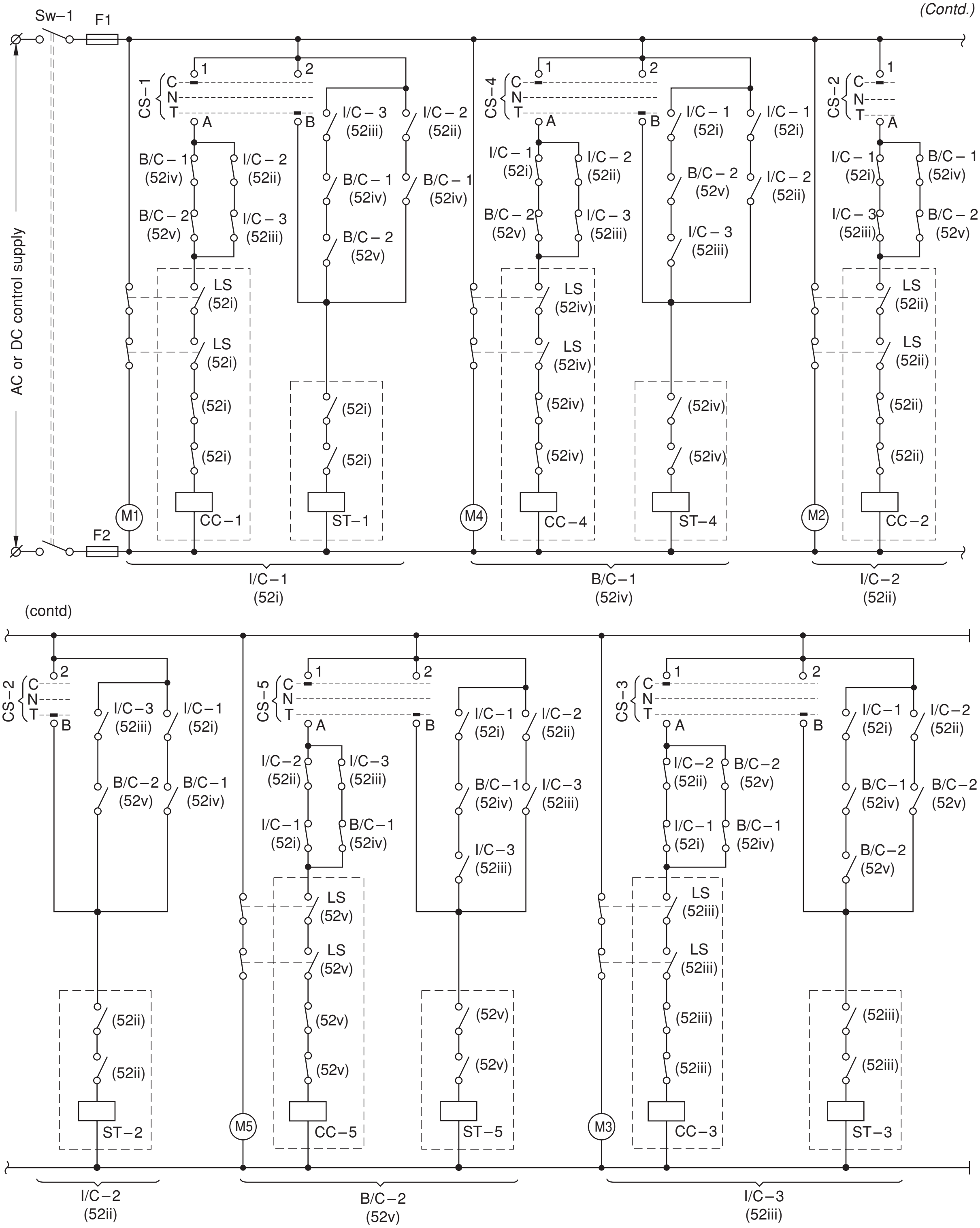
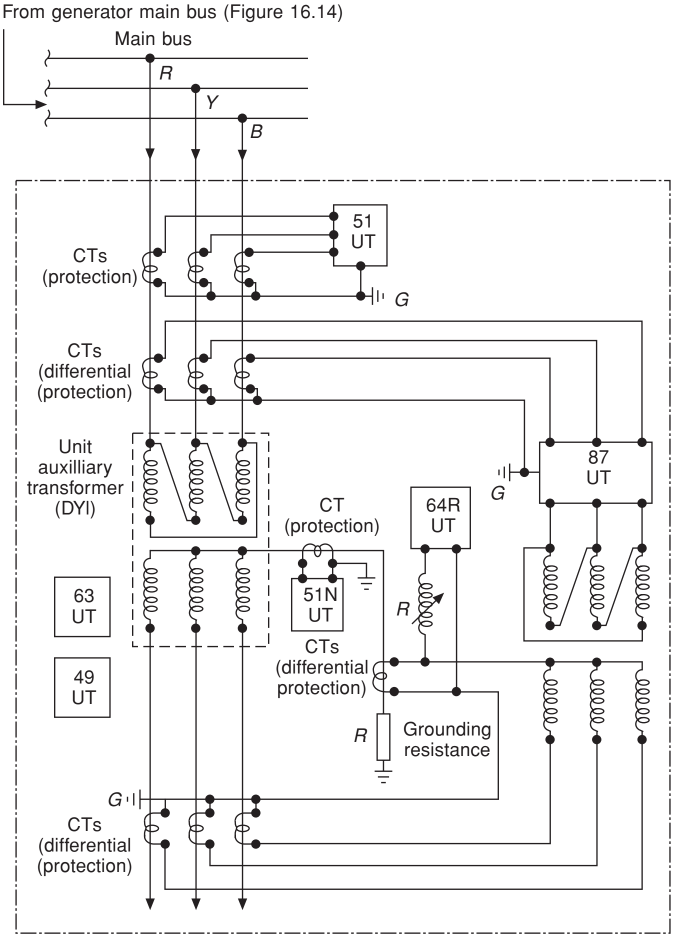
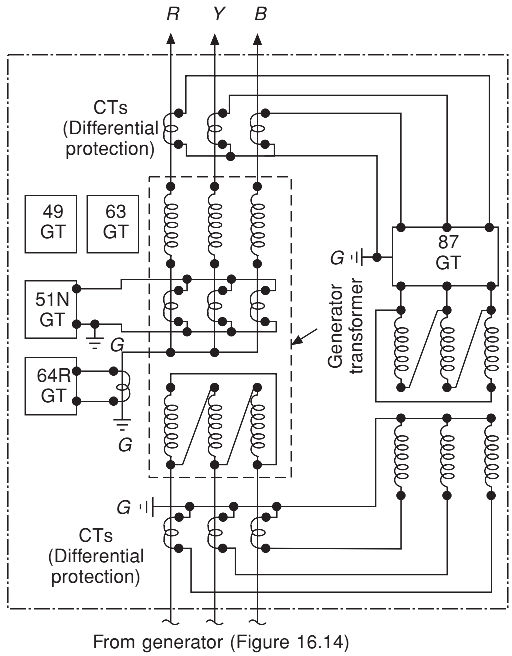


Figure 13.47 Control scheme for three electrically operated breakers, two bus couplers and three sources of supplies



49–UT : 'RTD' protection
51–UT : Over-current protection
51N–UT : Ground fault protection
63–UT : Gas protection
87–UT : Differential protection
64R–UT : Restricted ground fault protection

Figure 13.47(a) Protection scheme for a unit auxiliary transfomer (UAT)



49–GT : 'RTD' protection
51N–GT : Ground fault protection
63–GT : Gas protection
64R–GT : Restricted ground fault protection
87–GT : Differential protection

Figure 13.47(b) Protection scheme for a generator transfomer (GT)

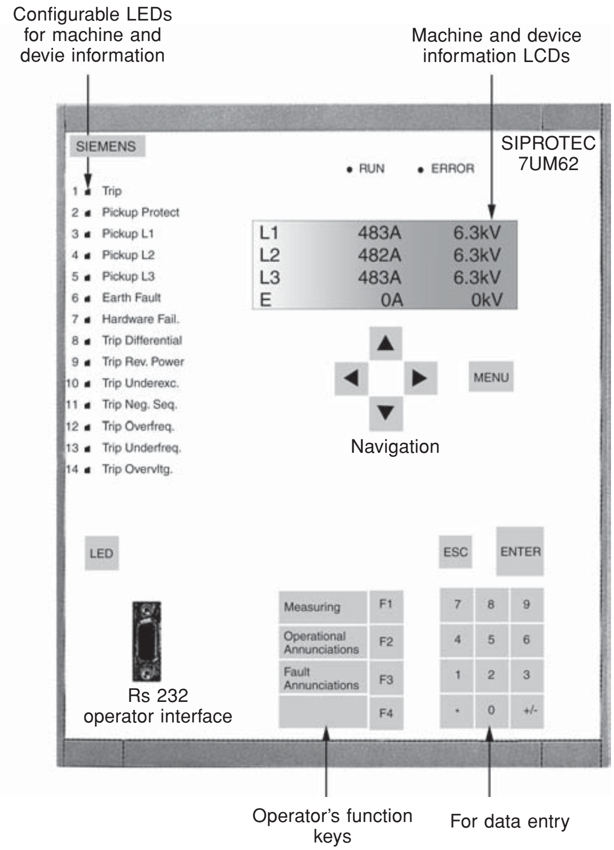
Over-current protection
Over-current protection is normally not provided in generator and generator transformers to save the machines from likely outages on momentary over-loads and retain the stability of the system. In the event of over-loading, the normal practice is to shed some of the loads on the transmission network. For details see Section 16.8.2 item 'e' under 'large power stations'. (See also power management through SCADA system (Section 24.11))

51N-GT Ground fault protection
63-GT Gas protection through a Bucholtz relay
64R-GT Restricted ground fault protection
87-GT Differential protection to detect a phase-to-phase fault.

Note
Relay Code numbers are according to ANSI designations, Table 13.18.

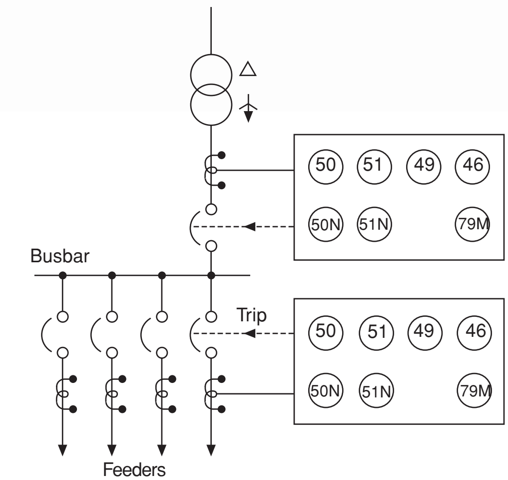
(iv) ***Feeder protection:*** A typical scheme is shown in Figure 13.47(c). This can be modified according to system requirements or equipment needs
(v) ***Restricted ground fault protection*** (Section 21.6.2)
(vi) ***Unrestricted ground fault protection*** (Section 21.6.3)
(vii) ***Directional ground fault protection*** (Section 21.6.4)
(viii) ***For the application of microprocessor*** based numerical relays in the automation of power generation, transmission or distribution of power as for a power management EMS (energy management system) or DMS (distribution management system) – SCADA system (Section 24.11).

Front view of a differential protection relay for transformers, generators, motors and busbars (Courtesy: Siemens)



Front view of a multifunction generator, motor and transformer protection relay (Courtesy: Siemens)

Note
The state-of-the-art micro-processor based relays combine many relay units in one and it is not possible to assign a code number to a relay that may vary from manufacturer to manufacturer. For protection available in a relay one may see the features of the relay being chosen. The relays can also be custom built for a given application.



Note
Relays considered necessary and not shown can be incorporated and those not necessary and shown can be deleted

Figure 13.47(c) Typical feeder protection and views of a few relays

13.9 General guidelines during installation and maintenance of a switchgear or a controlgear assembly

1 **Installation and fixing** The assembly should be installed in a room that is well ventilated (except for outdoor assemblies), on a rigid concrete or steel foundation to eliminate vibrations. A simple and more common practice of fastening on a separate steel foundation frame is illustrated in Figures 13.48(a) and (b). The assembly may also be fixed on a concrete foundation directly, but this will be found to be more cumbersome and time-consuming.

2 **While putting into service**

- One may follow field tests as discussed in Section 14.5 before putting the switchgear or the controlgear assembly into service.
- If the insulation resistance is observed to be low the interior of the switchgear or the controlgear assembly should be dried out to attain the required

Table 13.17 A brief comparison of main aspects in various types of protective relays

S.No.	*Parameters*	*Electromagnetic*	*Static/Electronic (Analogue relays)*	*Numerical (Digital relays)*
1	Measuring elements and hardware	Induction disc, coils, electromagnets, induction cup, balance beam.	Discrete R, L, C, transistors, analogue ICs, comparators.	Microprocessors, digital ICs, digital signals processor.
2	Measuring method	Electrical quantities are converted into mechanical force (torque) that may rotate a disc to actuate a trip command.	They measure current and voltage quantities which are compared with the reference values in an analogue comparator to decide for a trip command.	They sample and convert the current and voltage quantities into digital (binary) values and use numerical algorithm technique to process the same in a digital microprocessor for trip decision.
3	Timing function	Mechanical clock, dashpot	Static timers	Counters
4	Sequence of events	Not possible	Not possible	Provided
5	Binary inputs for adaptive relaying	Not available	Not available	Freely marshallable
6	Case size	Bulky	Modular, compact	Most compact
7	Vibration proof	No	Yes	Yes
8	CT loading/burden	8–10 VA	1 VA	<0.5 VA
9	Harmonic immunity	No	Possible through analogue filtering	Yes, digital filtering is incorporated
10	Calibration	Frequently required as settings drift due to ageing	Required as settings drift due to ageing	Not required as settings are stored in memory in digital format.
11	Electromagnetic/ electrostatic high frequency disturbances (EMI effects)	Immune (because compared to its own magnetic field, EMI inferences may be feeble)	Susceptible*	Immune
12	Multiple characteristics	Not possible	Not possible	Possible
13	Integrated protective functions	Not possible	Not possible	Possible
14	Range of settings	Limited	Wide	Wide
15	Fault disturbance recording	Not possible	Not possible	Possible
16	Digital communication port	Not possible	Not available	Available
17	Status**	Prominent until about 1970s	Prominent during 1970–2000	A state-of-the-art relay

* Shielding of signals: In case of static relays it is essential to protect the control signals from getting corrupted by electromagnetic and electrostatic interferences (EMIs) by using shielded (screened) or fibre optic control cables for control wiring (also see Section 13.3.6).

** Gradually electromagnetic (or electromechanical) and analogue (static) relays are phasing out in preference to numerical relays.

value before energizing it. The procedure to dry the moisture is similar to that for motors and is discussed in Section 9.5.2. In this case during the heating-up period the insulation resistance may first drop and reach its minimum, stabilize at that level and then start to rise gradually. Continue the process until it reaches its required level as shown in Table 14.7.

- In HV as well as LV switchgear assemblies provide a surge arrester or a lightning arrester, wherever necessary. Also refer to Section 17.11.
- It is advisable that all the protective devices provided in the assembly be set to their minimum values to ensure fast tripping. They can be adjusted for proper settings when putting the assembly into service.

3 Maintenance of busbars and busbar connections

- All the joints, particularly power joints at the main busbars, tap-offs and cable ends, should be checked periodically for any pitting or loosening. Also check the contact resistance to ensure a good joint as noted at item 9, Section 13.7.3. Such checks are recommended at every six months of operation and must be carried out meticulously, particularly for aluminium busbar joints and cable terminations. Aluminium is a highly malleable and ductile metal and under high temperatures and pressures has a tendency to run out and loosen its grip. At locations that are critical, contaminated or humid, or that are subject to vibrations, the period of maintenance checks may be reduced based on experience. A logbook can also be maintained to monitor the variance in important parameters and to take preventive measures during operation.
- **Draw-out components**
  – In a draw-out MCC all current-carrying components should be periodically checked for their silver-

Table 13.18 ANSI standard device function numbers

Device number	*Function*	*Device number*	*Function*	*Device number*	*Function*
1	Master element	37	Undercurrent under power relay (low forward power relay)	65	Governor
2	Time-delay relay	38	Bearing protective device	66	Notching or jogging device
3	Checking or interlocking relay	39	Mechanical condition monitor	67	A.C. directional overcurrent relay
4	Master contactor	40	Field relay or loss of excitation relay	67N	Directional ground fault relay
5	Stopping device	41	Field circuit breaker	68	Blocking relay
6	Starting circuit breaker	42	Circuit breaker, contactor, or starter	69	Permissive control device
7	Anode circuit breaker	43	Manual transfer selector device or local/remote selector switch	70	Rheostat
8	Control power disconnecting device	44	Unit sequence starting relay	71	Level switch
9	Reversing device	45	Atmospheric condition monitor	72	D.C. circuit breaker
10	Unit sequence switch	46	Reverse phase or negative sequence relay	73	Load-resistor contactor
11	Reserved for future application	47	Phase sequence voltage relay	74	Alarm relay
12	Overspeed device	48	Incomplete sequence relay	75	Position changing mechanism
13	Synchronous speed device	49	Thermal overload relay	76	D.C. overcurrent relay
14	Underspeed device	50	Instantaneous overcurrent relay	77	Pulse transmitter
15	Speed frequency matching device	50D	Definite time delay overcurrent relay	78	Phase-angle measuring or out of step relay
16	Reserved for future application	50N	Instantaneous ground fault relay	79	Auto reclosing relay
17	Shunt or discharge switch	51	Inverse time overcurrent relay	80	Flow switch
18	Accelerating or decelerating device	51N	Inverse time ground fault relay	81	Underfrequency relay
19	Starting to running transition contactor	51GN	Inverse time generator ground fault relay	82	D.C. reclosing relay
20	Electrically operated valve	51v	Voltage controlled overcurrent relay	83	Automatic selective control or transfer relay
21	Distance relay	50/51	IDMT with instantaneous overcurrent relay	84	Operating mechanism
22	Equalizer circuit breaker	52	A.C. circuit breaker	85	Carrier pilot-wire receiver relay
23	Temperature control device	53	Exciter or D.C. generator relay	86	Lock-out relay
24	Reserved for future application	54	Reserved for future application	87	Differential protective relay
25	Synchronizing check relay	55	Power factor relay	88	Auxiliary motor or motor generator
25G	Guard relay	56	Field application relay	89	Disconnecting switch
27	Undervoltage relay	57	Short-circuiting or grounding device	90	Regulating device
28	Flame detector	58	Rectification failure relay	91	Voltage directional relay
29	Isolating contactor	59	Overvoltage relay	92	Voltage and power direction relay
30	Annunciator relay	60	Voltage or current balance relay	93	Field-changing contactor
31	Separate excitation device	61	Reserved for future application	94	Anti-pumping relay
32	Directional reverse power relay	62	Time-delay stopping or operating relay	95	Supervision relay
33	Position relay	63	Bucholtz relay	96, 97	Used for specific applications where other symbols are not suitable
34	Master sequence device	64	Restricted ground fault relay	98	Fuse failure relay
35	Brush operating or slip-ring short-circuiting device			99	Motor protection relay
36	Polarity or polarizing voltage device			Y	Auxiliary relay

Based on ANSI/IEEE C 37.2

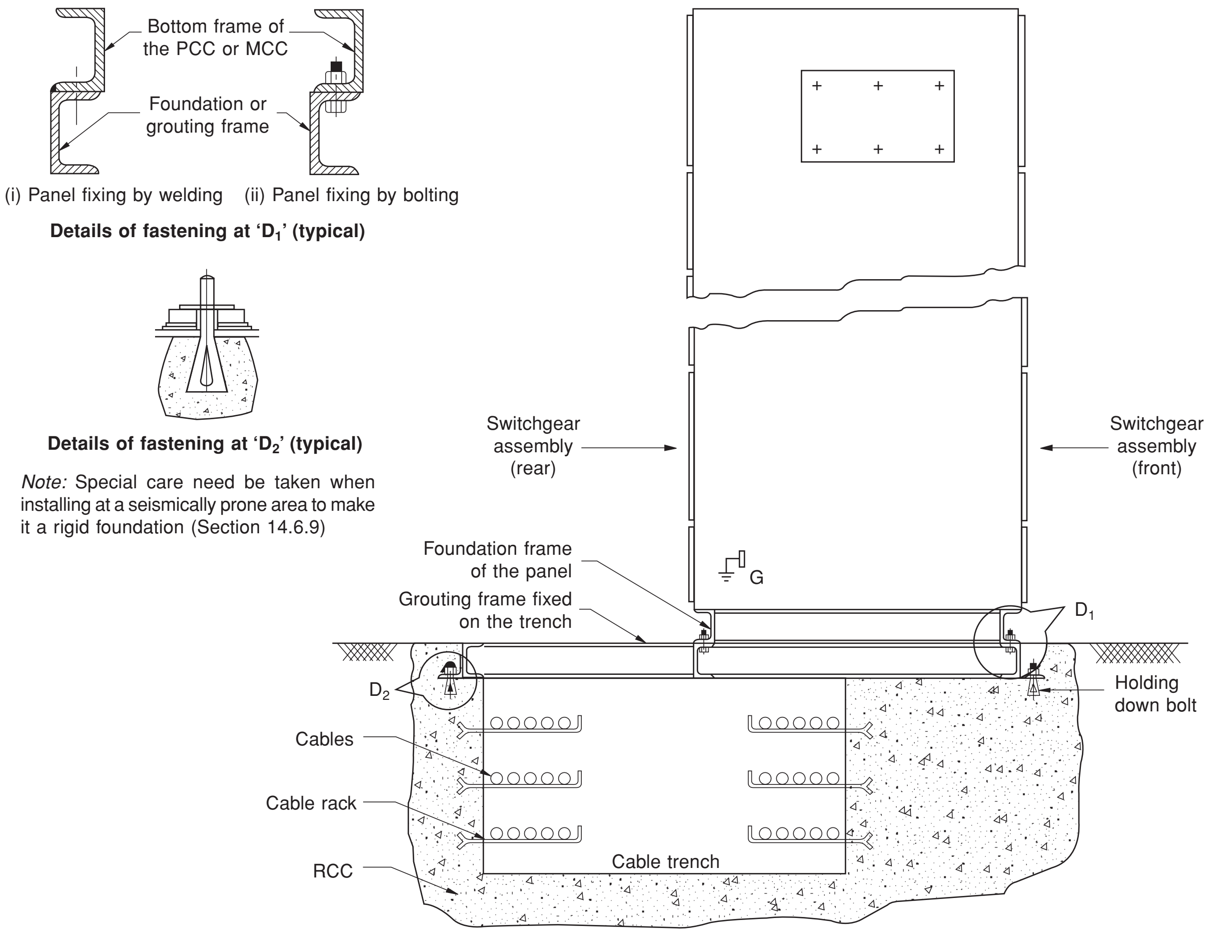


Figure 13.48(a) Illustration of a typical installation of high-rating switchgear assembly on a cable trench

plating, proper contact area, spring pressure and tightness of joints (this procedure can follow the manufacturer's maintenance schedule) or at least during the six-monthly or yearly maintenance check-ups of the busbars and the busbar joints as noted above. The contacts or their springs may be replaced when the contacts are worn out or the silver-plating is withered. Silver prevents oxidation of copper contacts and also eliminates bimetallic corrosion.

Note

Tarnishing (blackening) of contacts is a common characteristic of silver-plated contacts. It is the formation of silver oxide film which is a good conductor of heat and electricity and is not a cause for concern.

– Clean and lubricate all the main incoming and outgoing power contacts as well as the auxiliary sliding contacts at least once a year. Use of neutral grease as noted in Section 13.6.1(iv) is recommended. A properly greased contact will also help to avoid a flashover.
– For cleaning of contacts, use white petrol or carbon tetrachloride or perchloro-ethylene. Never use sandpaper for it may damage the silver-coating and also render the surface uneven which may cause arcing and pitting during operation. While cleaning, care must be taken that the solvent does not reach the insulating components.
– The cranking screw and the guide rails on which the trolley slides must also be coated with ordinary grease to provide a smoother operation and to prevent corrosion.
– Check the grounding contacts periodically for their positive ground connections.

For the sake of brevity, this subject is not dealt in with great detail here. For more details refer to IEC 60694 and BS 6423.

4 **Discharging of a power capacitor** Whenever power capacitors are installed in a switchgear assembly and are not discharged automatically on a switch OFF, through its own interrupting device, these must be discharged manually by grounding its terminals before its feeder devices and components are physically handled.

5 **Prevention from whisker formation** Whisker sprouting is sort of metallic hair or filament like growth on silver plated contacts at high temperatures and moisture. This phenomenon is usually seen to occur in environments contaminated with sulphur (S), its oxides (SO_2) and sulphides (H_2S) such as in chemical

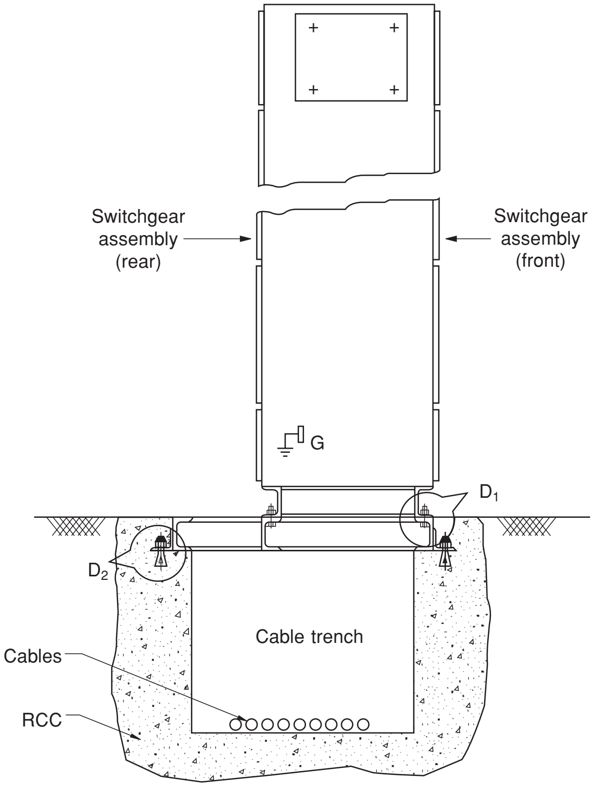


Figure 13.48(b) A typical installation of a low-rating switchgear assembly on a cable trench

factories and their surroundings. Though a rare phenomenon, can be catastrophic, as it can cause short circuit with an adjacent live part. Maintenance staff working on a dead feeder have experienced electrical shocks as some of the live parts of an adjacent feeder or busbars was making contact with this feeder due to whisker formation.

Since silver or tin plated surfaces do not corrode hence the phenomenon of metallic whisker growth at such surfaces. It usually occurs at high temperatures 100°C and above. In presence of moisture sulphur forms silver sulphide (Ag_2S) or tin sulphide (SnS) that makes a good surface for whisker growth. It can also cause pitting of contacts of the same phase as a consequence of sparking between draw-out contacts of ACBs and contacts of draw-out feeders. For more details and research work on this phenomenon see reference 9 under Further Reading.

Since total isolation of switchgear components and bus systems from such environments may not be practical unless the switchroom itself is pressurized (Sections 7.13.3 and 13.4.2), an easy solution to protect the silver or tin plated conducting surfaces from S and its compounds is to apply adequate grease at all exposed conducting surfaces and keep a close monitoring of the same. Locating the assemblies away from such environments without pressurizing the room may not mitigate the problem as sulphur fumes in the atmosphere may still attack the silver or tin plated surfaces and cause the whisker formation.

13.10 Power circuits and control scheme diagrams

For a ready reference to the readers, we provide power and control scheme diagrams, usually required in day-to-day use, while wiring an MCC or a control panel, or maintenance at site.

All the control circuits are based on conventional electrical and electromagnetic (auxiliary contactors and timers) controls. The latest trend for large or complicated controls, however, is to have more compact, accurate and quick-responding PLC and microprocessor-based controls, as discussed in Section 13.3.6. The logistics for PLCs or microprocessors are also the same as for electromagnetic controls.

13.10.1 Interlocking and control scheme for a typical air-conditioning plant

For the application of individual schemes, as illustrated above and an easy understanding of these schemes, we consider below a conventional type of air-conditioning plant for its various controls, interlocks and operating requirements.

This type of air-conditioning plant may have the following three closed circuits:

1 Refrigerant circuit: Figure 13.49(a) is a flow diagram for the refrigerants. The refrigerant hitherto used was chloro-fluoro carbon (CFC-11, 12, 113, 114 or 115) but use of this gas is almost discontinued as this caused ozone layer depletion and global warming. It is being gradually replaced by hydro-chloro-fluoro carbons (HC FC-22, 123, 141 and 142). But this too is not totally environment friendly and shall be replaced by 2040 (latest) by hydro-fluoro carbons (HFC-134a) which will be safer. However, research is on to invent yet better blends of refrigerants which may be quite environment friendly. [For more information on refrigerants refer to UNEP IE/PAC (United Nations Environment Programme, Industry and Environment Programme Centre, USA)].
2 Condenser water circuit: Figure 13.49(b) is a flow diagram for the condenser water.
3 Chilled water circuit: Figure 13.49(c) is a flow diagram for the chilled water.

The power circuit single-line diagram is shown in Figure 13.50. The following are the controls and protections that may be generally required for such a plant.

Compressor

Control of the compressor is achieved by engaging the required number of cylinders. In, say, a 16-cylinder compressor if we engage only four cylinders, the compressor will run at 25% capacity, and if we engage eight cylinders, the compressor will run at 50% capacity. Electrically operated solenoid valves are provided for capacity control. Energy can be conserved by using static controls, as discussed in Section 6.15.

For protection and temperature control of the compressor the following safety devices may be provided:

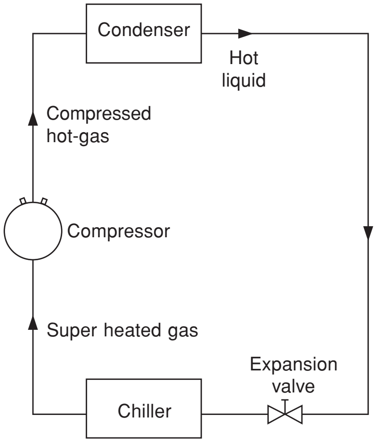


Figure 13.49(a) Refrigerant circuit (typical)

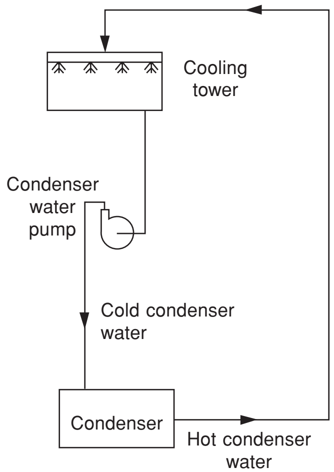


Figure 13.49(b) Condenser water circuit (typical)

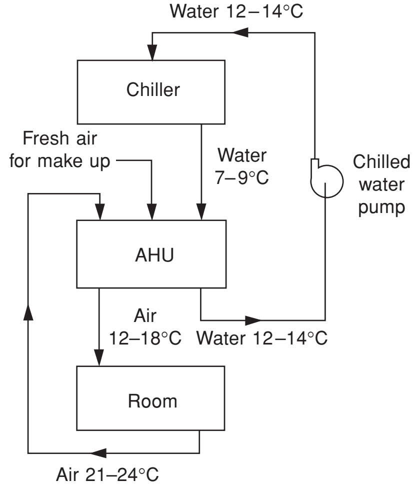


Figure 13.49(c) Chilled water circuit (typical)

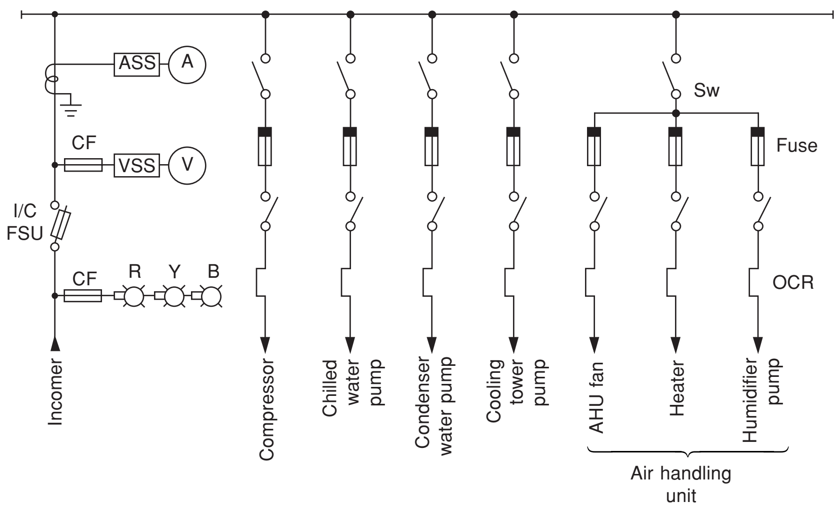


Figure 13.50 Single line power diagram for a typical air conditioning plant

- Water flow switches
- High/low pressure cut-outs
- Lube oil pressure switch and
- Safety thermostat

Air-handling unit (AHU)

To control the room temperature flow of chilled water is controlled in AHU, Figure 13.49(c). A thermostat senses the room condition and activates a motorised or solenoid valve in AHU coil which in turn adjusts the flow of chilled water to the required level. There are other methods also in practice such as bypass of certain amount of air through coil and variable speed fan drive (for energy conservation) (Section 6.15).

Humidity control

To control the humidity in a conditioned space humidifiers and reheaters are provided in AHU. Humidifiers to increase and reheaters to decrease the humidity.

Electrical interlocks between the drives

The following interlocks are generally provided between the various drives:

- The condenser water pump will not start unless the cooling tower fan is already running.
- The chilled water pump will not start unless the condenser water pump is also running.
- The compressor will not start unless the chilled water and condenser water pumps are also running.

The control and protection scheme diagram for all the above requirements is given in Figure 13.51. It is presumed that all the drives are provided with direct on-line switching.

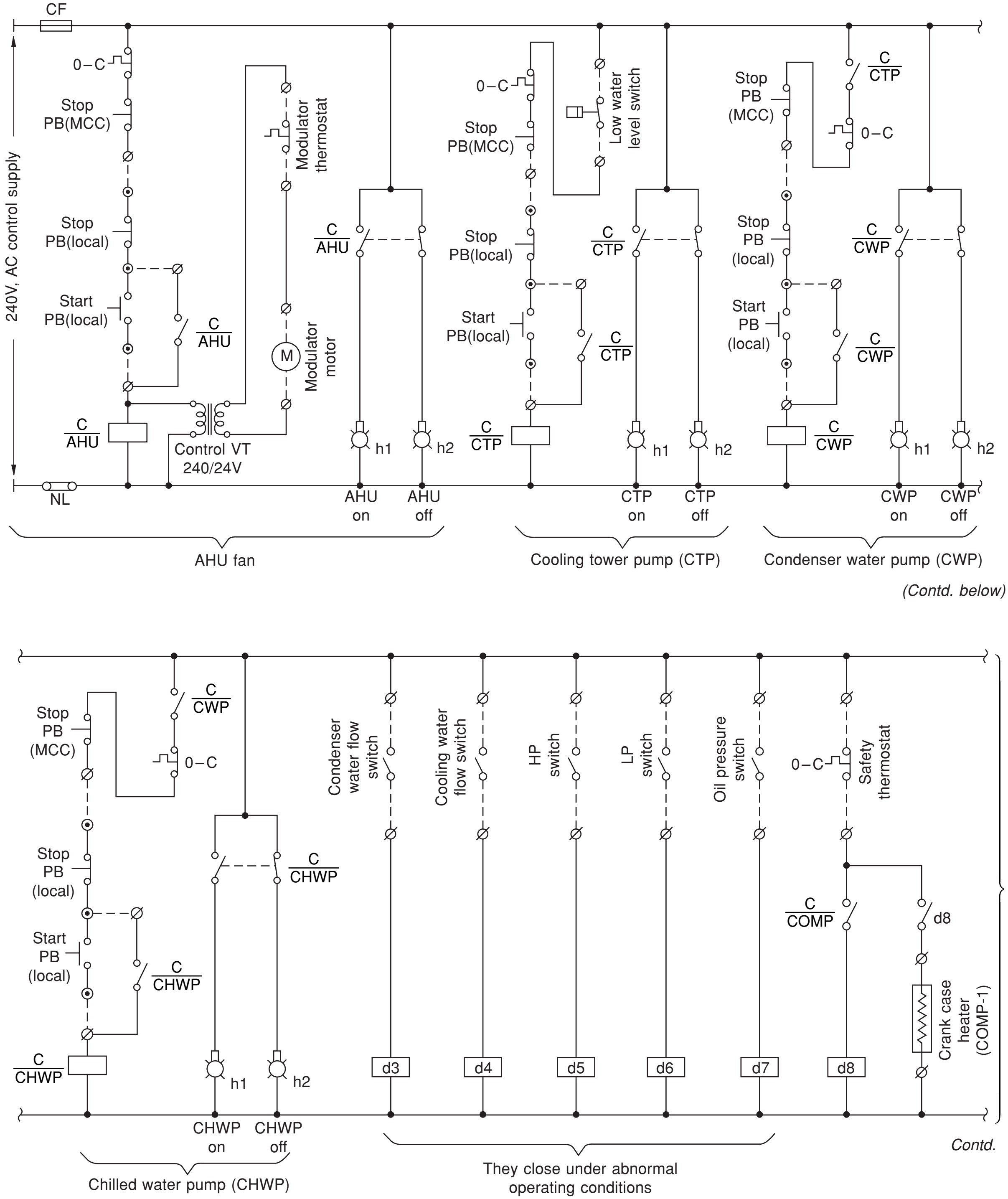


Figure 13.51 *(Contd.)*

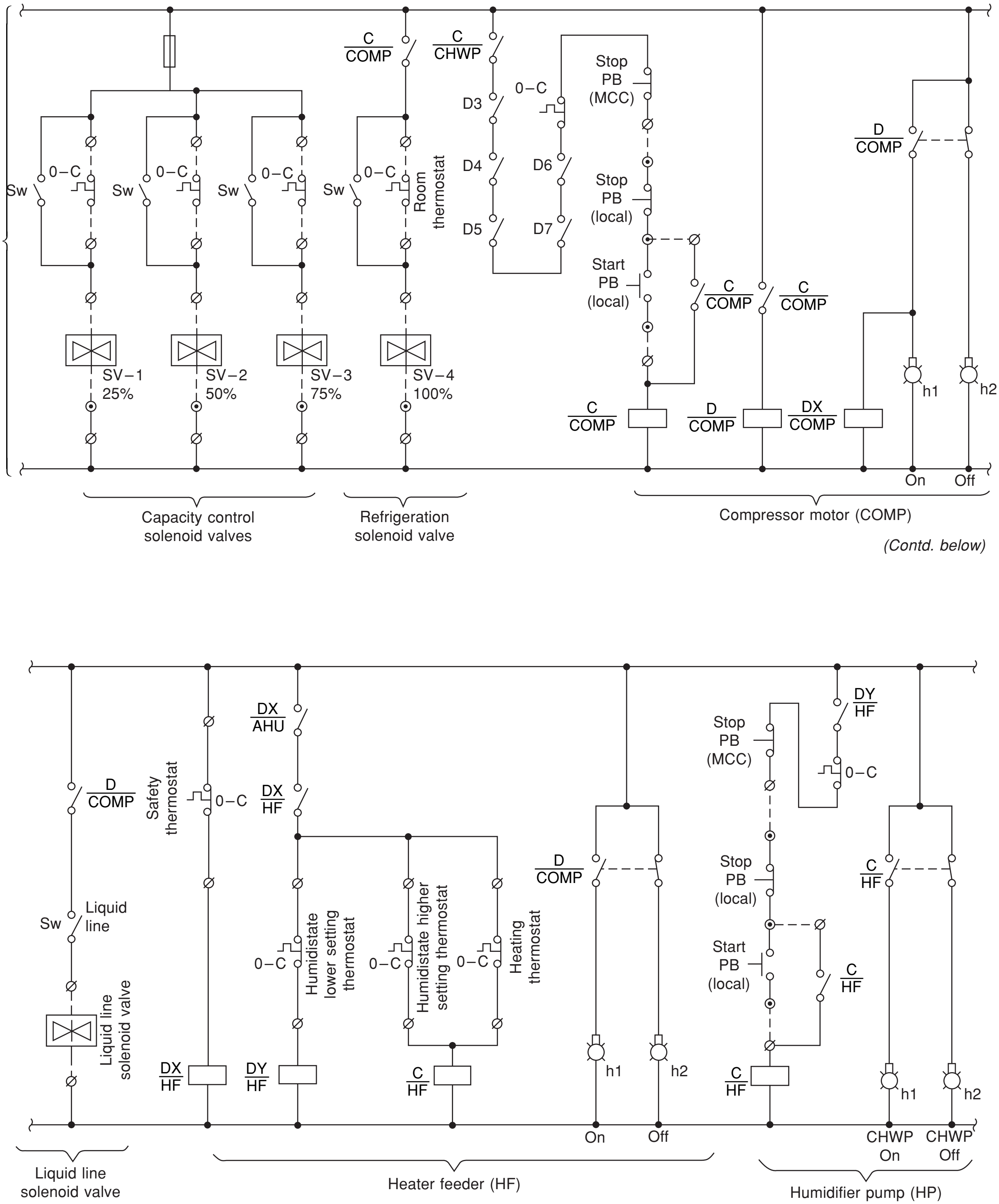
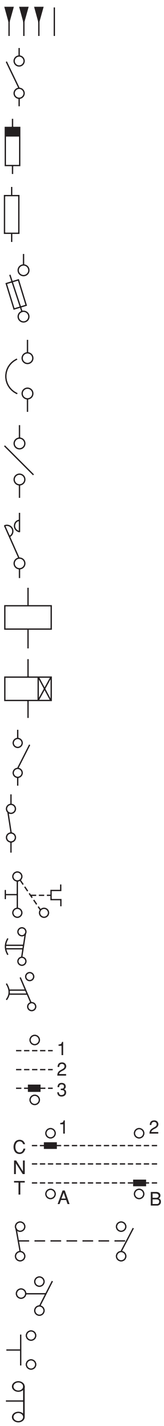
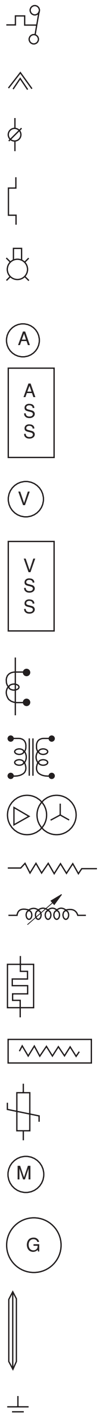


Figure 13.51 Control, protection and interlocking scheme for the air conditioning plant of Figure 13.50

Table 13.19 List of symbols and abbreviations used



Symbol	*Abbreviation*	*Description*
	RYBN	3ϕ and neutral power supply
	Sw	Heavy-duty switch
	F	Power fuse
	CF	Control fuse
	FSU	Fuse switch unit
		MCB/coupler/circuit breaker
		Isolator
	C	Power contactor (M – main, D – delta, S – star)
	c d	Coil of main contactor Coil of auxiliary contactor
	T	Coil of timer
		Normally open auxiliary contact
		Normally closed auxiliary contact
	OCR	Overcurrent relay
	TDC TDO	Time delay contacts
	S/Sw	Selector switch (L/R – local/remote, A/M– auto/manual)
		Breaker control switch (spring return to neutral) (C – closed, N – neutral, T – trip)
	LS	Limit switch with spring charging mechanism
	DS	Door switch
	Start PB Stop PB	Pushbutton (colour of knob, R – red, G – green, Y – yellow)



Symbol	*Abbreviation*	*Description*
	TH	Thermostat
	D/O	Drawout terminal
		Terminal
	O/C	Thermal overcurrent relay
	h	Indicating light (colour of lens, R–red, G–green, A–amber, W–white)
	A	Ammeter
	ASS	Ammeter selector switch
	V	Voltmeter
	VSS	Voltmeter selector switch
	CT	Current transformer
		Voltage or control transformer
	Tr	Power Transformer
	R	Resistance
	L	Reactance
	CS	Current shunt
	SH	Space heater
		Surge arrester
	M	Motor
	G	Generator
		Cable
	G	Grounding

13.10.2 Different types of starters and instruments wiring schemes

Table 13.19 provides the list of symbols and abbreviations used.

Figure 13.52	–	Simple DOL starter
Figure 13.53	–	DOL starter with provision for remote control and starting and/or running interlocks
Figure 13.54	–	DOL starter with CT-operated over-current relay (i) For a high-rating motor or (ii) For a heavy-duty motor (having prolonged starting time) (irrespective of rating)
Figure 13.55	–	Reversing DOL starter
Figure 13.56	–	Star-delta starter
Figure 13.57(a)	–	Auto transformer starter using pneumatic timer
Figure 13.57(b)	–	Auto-transformer starter using electronic timer
Figure 13.58	–	Primary resistance starter
Figure 13.59	–	Dual-speed starter
Figure 13.60	–	Three stage stator-rotor starter
Figure 13.61	–	Schematic for panel space heater and internal illumination
Figure 13.62	–	Schematic for instrument wiring

Note
All control schemes shown with auxiliary contactors and timers can be easily replaced with PLCs and microprocessor-based controls. Refer to Section 13.3.6 for more details.

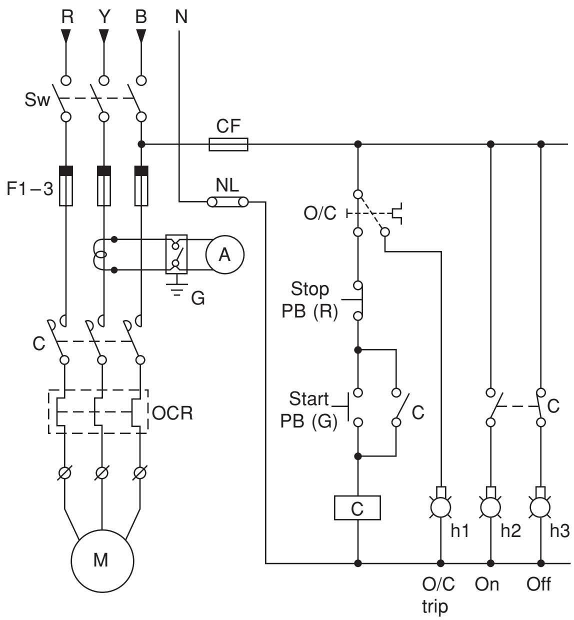


Figure 13.52 Simple DOL starter

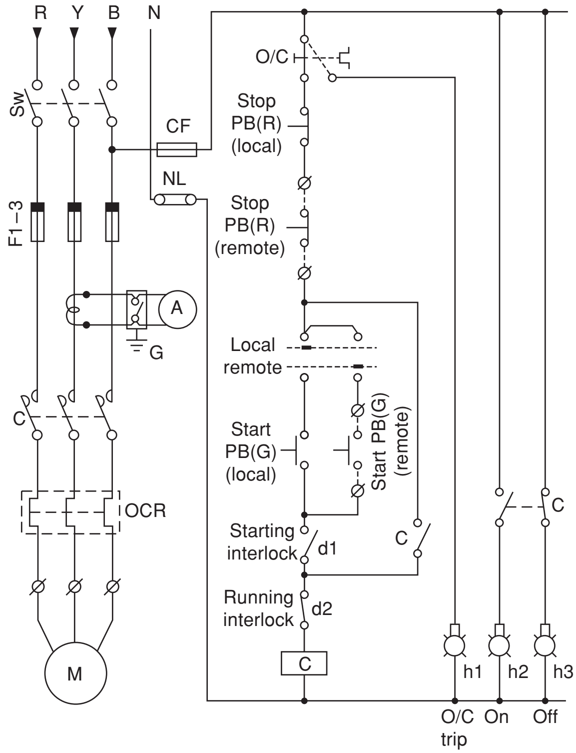


Figure 13.53 DOL starter with provision for remote control and starting and/or running interlocks

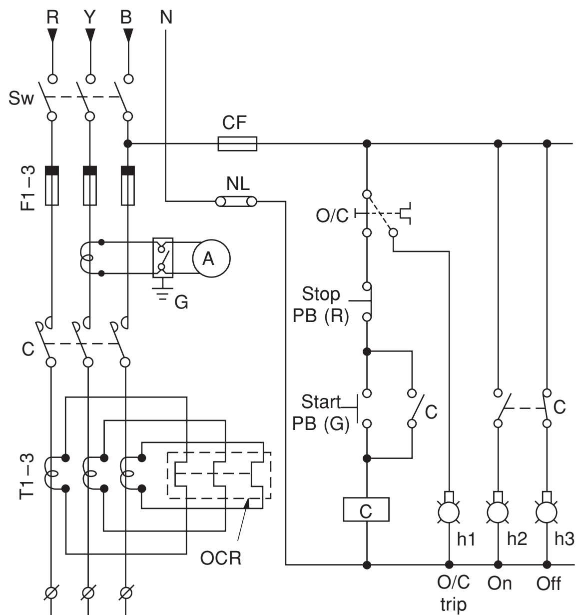


Figure 13.54 DOL starter with CT-operated over-current relay
(i) For a high-rating motor or
(ii) For a heavy-duty motor (prolonged starting time) (irrespective of rating)

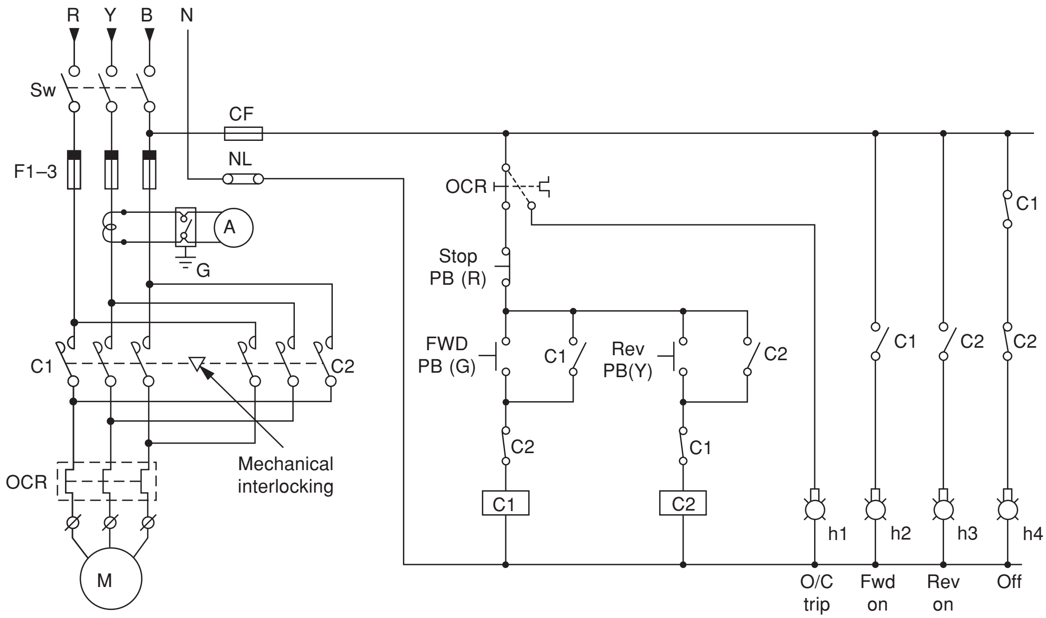


Figure 13.55 Reversing DOL starter

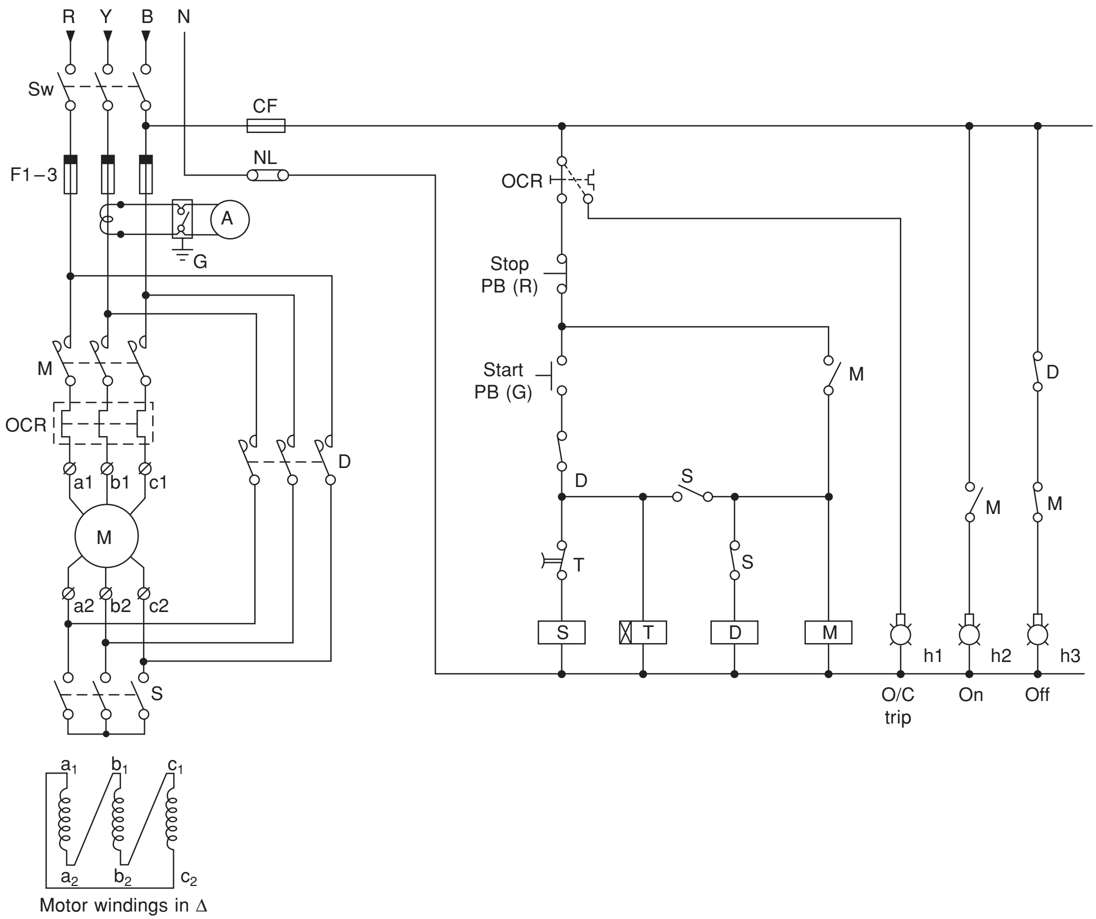
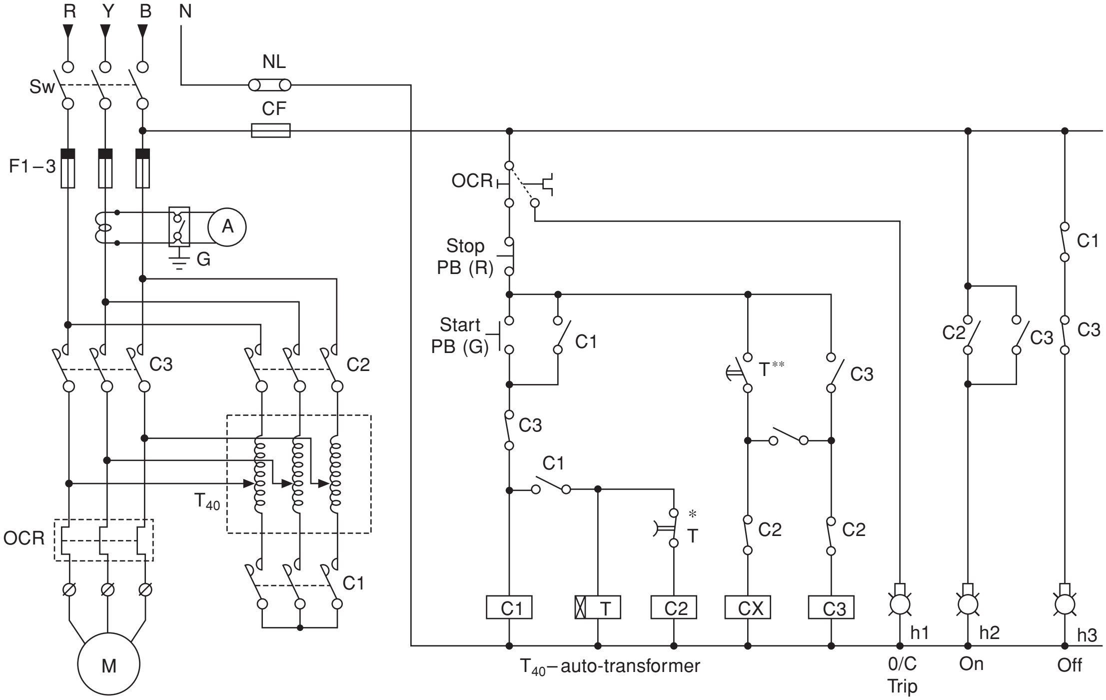
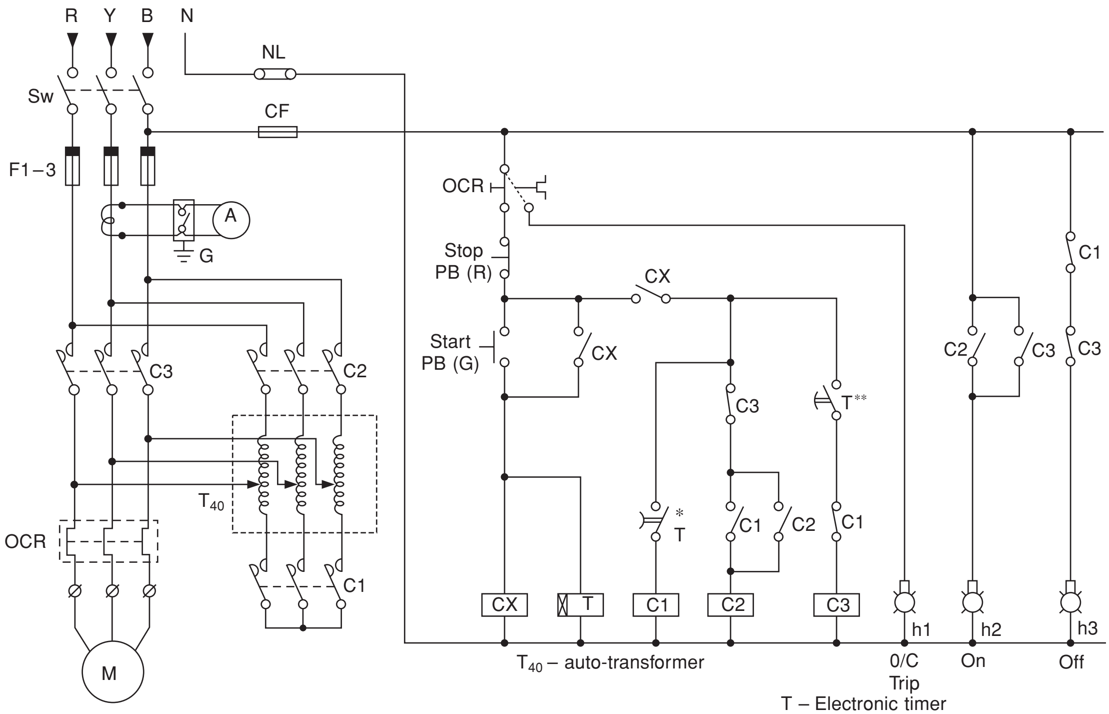


Figure 13.56 Star-delta starter



T – Penumatic timer on delay
* – Normally closed, time delay open
** – Normally open, time delay closed

Figure 13.57(a) Auto-transfomer starter using pneumatic timer



T – Electronic timer
* – Normally open, instantaneous close and time delay open
** – Normally open, time delay closed

Figure 13.57(b) Auto-transformer starter using electronic timer

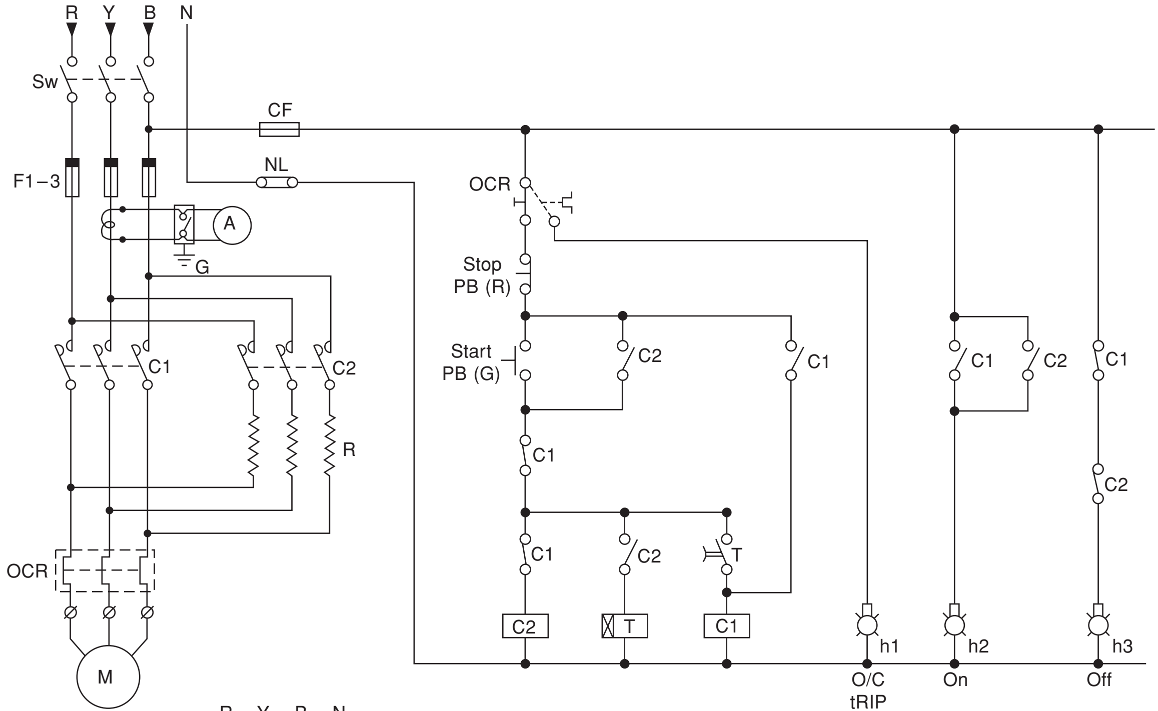


Figure 13.58 Primary resistance starter

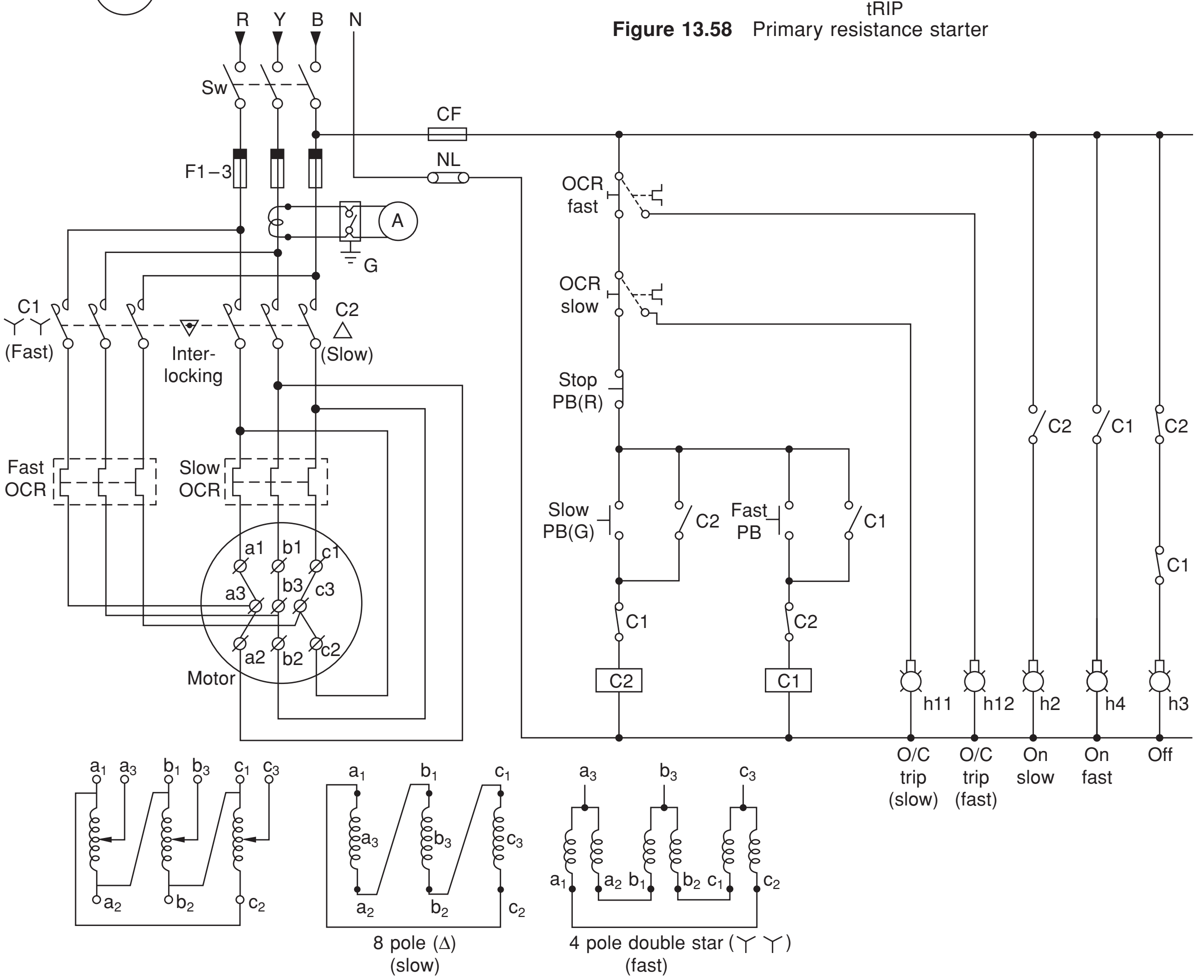


Figure 13.59 Dual-speed starter

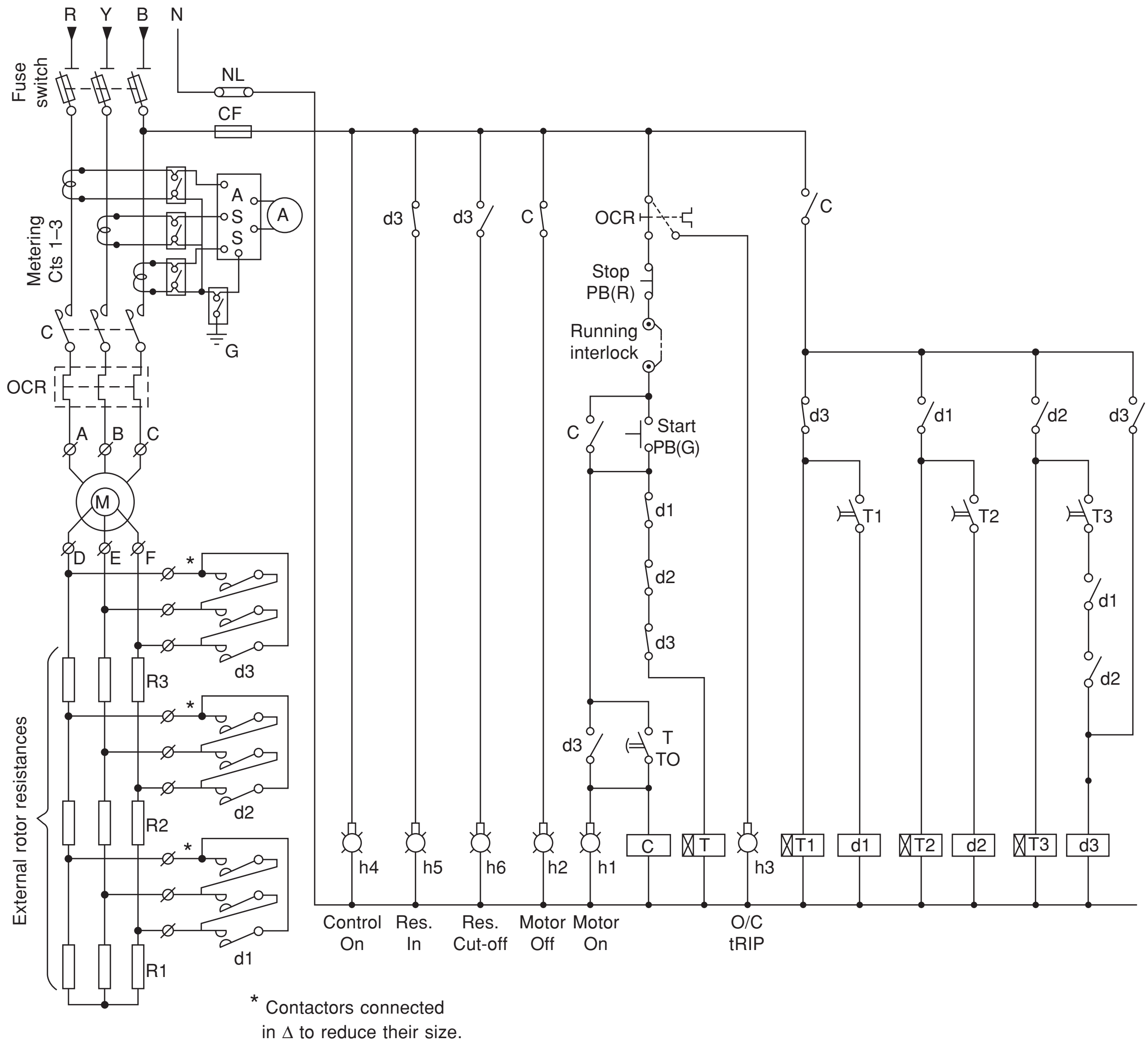
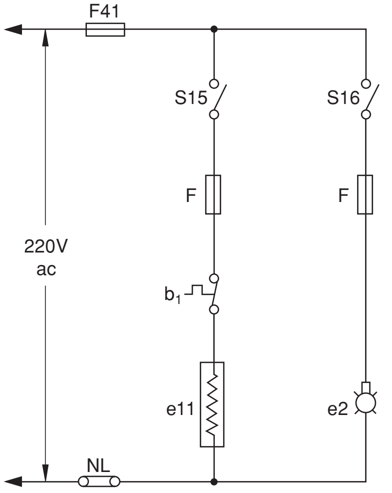


Figure 13.60 Typical three-stage stator-rotor starter



b1 — Thermostat cut off contact
S15 — Space heater switch
S16 — Panel door switch
e11 — Space heater
e2 — Interior illumination

Figure 13.61 Schematic for panel space heater and internal illumination

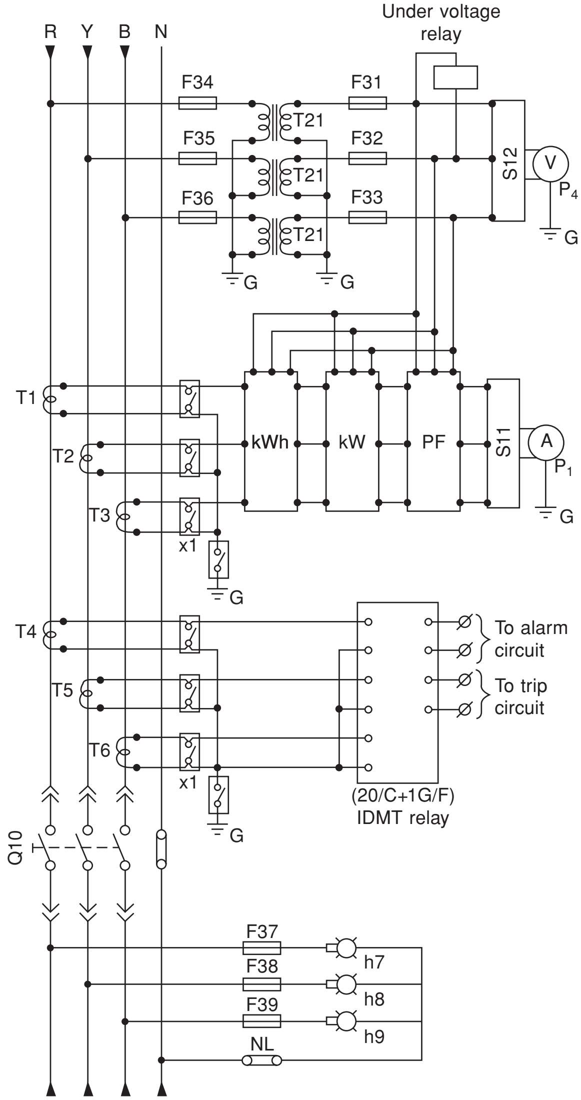


Figure 13.62 Schematic for instruments' wiring

Relevant Standards

IEC	*Title*	*IS*	*BS*	*ISO*
60034-1/2004	Rotating electrical machines. Rating and performance.	4722/2001, 325/2002	BS EN 60034-1/1998	–
60038/1994	IEC standard voltages.	–	–	–
60044-1/2002	Current transformers, specification and application.	2705-1 to 4/2002, 4201/2001	BS 7626/1993	–
60044-2/2003	Application guide for voltage transformers. General requirements for voltage transformers. Measuring voltage transformers.	4146/2001, 3156-1/2002, 3156-2/2002	BS 7729/1995 BS EN 60044-2/1999	–
60051-1/1997	Direct acting indicating analogue electrical measuring instruments and their accessories. Definitions and general requirements.	1248-1 to 9	BS 89-1 to 9/1990	–
60059/1999	Standard current ratings (based on Renald Series R-10 of ISO-3).	–	–	3/1973
60071-1/1993	Insulation coordination phase to earth – Principles and rules.	2165-1/2001	BS EN 60071-1/1997	–
60071-2/1996	Insulation coordination phase to phase – Principles and rules.	2165-2/2001	BS EN 60071-2/1997	–
60076-1/2000	Power transformers – General specification for tapping and connections.	2026-1/2001	BS EN 60076-1/1997	–
60079-1/2003	Construction and verification test of flameproof enclosures of electrical apparatus – Enclosure ‘d’.	2148/1998	BS 4683-2/1993, BS EN 50018/2000	–
60079-14/2002	Electrical installations in hazardous areas (other than mines).	5572/1999	BS EN 60079-14/2003	–
60112/2003	Method of test for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions.	–	BS EN 60112/2003	–
60255-3 to 26	Electrical relays for power system protection. General requirements. Applications.	3231-1 to 3/2001 3842-1 to 12/2001	BS EN 60255-1 to 18	–
60258/1976	Direct acting recording electrical measuring instruments and their accessories.	–	BS 90/1993	–
60265-1/2000	Switches and switch isolators for voltages above 1000 V – up to 52 kV. General and definitions.	9920-1/2002	BS EN 60265-1/1998	–
60265-2/1998	High voltage switches for rated voltages of 52 kV and above.	9920-2/2001	BS EN 60265-2/1994	–
60282-1/2002	High voltage fuses. Current limiting fuses exceeding 1 kV. Application guide.	9385-1/2002 9385-3/2002	BS EN 60282-1/2002	–
60439-1/2004	Low voltage switchgear and controlgear assemblies. Requirements for type-tested and partially type tested assemblies.	8623-1/1998	BS EN 60439-1/1999	–
60439-2/2000	Low voltage switchgear and controlgear assemblies. Particular requirements for busbar trunking systems.	8623-2/1998	BS EN 60439-2/2000	–
60439-3/2001	Particular requirements for low-voltage switchgear and controlgear assemblies intended to be installed in places where unskilled persons have access to their use. Distribution boards.	8623-3/1998	BS EN 60439-3/1991	–
60439-4/2004	Low voltage switchgear and controlgear assemblies. Particular requirements for assemblies for construction sites.	–	BS EN 60439-4/2004	–
60529/2001	Specification for degrees of protection provided by enclosures (IP code).	4691/1999	BS EN 60529/1993	–
TR 60664-2-2/ 2002	Insulation coordination for equipment within low voltage systems – Interface considerations – Application guide	–	–	–

IEC	*Title*	*IS*	*BS*	*ISO*
60694/2001	Common specifications for high voltage switchgear and controlgear standards.	12729/2000	BS EN 60694/1997	–
60811	Series of standards on electric cables.	–	–	–
60865-1/1993	Short circuit current calculation of effects – Definition and calculation methods.	–	–	–
60865-2/1994	Examples of calculations.	–	–	–
60870-5-103/1997	Telecontrol equipment and systems – Transmission protocols.	–	–	–
60909-0/2001	Guide for short-circuit calculations in a 3-ϕ system – calculation of currents.	13234/2002	BS EN 60909-0/2001	–
60947-1/2004	Specification for low voltage switchgear and control gear. General rules.	13947-1/1998	BS EN 60947-1/2004	–
60947-2/2003	Low voltage switchgear and controlgear. General rules and test requirements.	13947-2/1993	BS EN 60947-2/2003	–
60947-3/2001	Specification for LV switchgear and controlgear. Switches, disconnectors, switch-disconnectors and fuse-combination units.	13947-3/1998	BS EN 60947-3/2003	–
60947-4-1/2001	Low voltage switchgear and controlgear. Contactors for voltages not exceeding 1000 V a.c. or 1200 V d.c.	13947-4-1/1998	BS EN 60947-4-1/2001	–
60947-8/2003	Low voltage switchgear and controlgear – control units for built-in thermal protection (PTC) for rotating electrical machines.	–	–	–
61000-4-6/2001	Electromagnetic compatibility (EMC) – Testing and measurement techniques. Immunity to conducted disturbances induced by radio-frequency fields.	–	–	–
61641/1996	Enclosed low voltage switchgear and controlgear assemblies. Guide for testing under conditions of arcing due to internal fault.	–	–	–
TR 61818/2003	Application guide for low voltage fuses.	–	–	–
61850 (1 to 10)	Communication networks and systems in substations.	–	–	–
62252/2002	Degree of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code).	–	–	–
62271-200/2003	A.C. metal enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV.	12729/2000	BS EN 60298/1996	–
62271-203/2003	Gas insulated metal-enclosed switchgear for rated voltages of 72.5 kV and above.	–	BS EN 60517/1997	–
–	Methods of testing plastics.	867/2003	BS 2782-0/2004	–
–	Mechanical properties of fasteners. Torsional test and minimum torques for bolts and screws with nominal diameters 1 mm to 10 mm.	1367-20/2001	BS EN 20898-7/1995	898-7/1992
–	Specification for spring washers for general engineering and automobile purposes. Metric series.	3063/1999	BS 4464/1990	–
–	Letter symbols and signs used in electrical technology – General guidance on symbols and subscripts	3722-1/1983	–	–
–	Application guide for electrical relays for a.c. systems.	3842-1 to 12/1967	–	–
–	Distribution pillars for voltages not exceeding 1000 V a.c.	5039/1983	–	–
–	Guide for marking of insulated conductors.	5578/1984		
–	Interconnecting busbars for a.c. voltages above 1 kV up to and including 36 kV.	8084/2002	BS 159/1992	–
–	Static protective relays	8686/1977	–	–
–	Code of practice for selection, installation and maintenance of switchgear and controlgear up to 1 kV. General.	10118-1/1991	–	–
–	Selection.	10118-2/2001	–	–

IEC	*Title*	*IS*	*BS*	*ISO*
–	Installation.	10118-3/2001	–	–
–	Maintenance.	10118-4/1991	BS 6423/1993	–
–	Requirements for mounting on rails in switchgear installations.	11039/1983	–	–
–	Preferred current ratings.	11955/1987	–	–
–	Specification for control transformers for switchgear and controlgear for voltages not exceeding 1000 V a.c.	12021/2000	–	–
–	General requirements for switchgear and controlgear for voltages not exceeding 1000 V a.c. or 1200 V d.c.	13947-1/1993	–	–
–	Code of practice for maintenance of electrical switchgear and controlgear for voltages above 1 kV and up to 36 kV.	–	BS 6626/1993	–
–	Code of practice for maintenance of electrical switchgear for voltages above 36 kV.	–	BS 6867/1993	–
–	Specification for voltage regulation and parallel operation of a.c. synchronous generators.	–	BS 4999-140/1987	–
–	Specification for dough moulding compounds for electrical purposes.	–	BS 5734-2/1990	–
–	Specification for sheet moulding compounds for electrical purposes.	–	BS 5734-4/1990	–

Relevant US Standards ANSI/NEMA and IEEE

ANSI/IEEE-141/1999	Recommended practice for electric power distribution for Industrial plants (*IEEE Red Book*).
ANSI/IEEE-241/1991	Recommended practice for electric power systems in commercial buildings (*IEEE Grey Book*).
ANSI/IEEE-242/2001	Recommended practice for protection and coordination of industrial and commercial power systems (*IEEE Buff Book*).
ANSI/IEEE-1312/1993	Voltage ratings for a.c. electrical systems and equipment above 230 kV.
ANSI/IEEE-1313.1/1996	Insulation Coordination – Definitions, principles and rules.
ANSI/IEEE-C37.16/2000	Preferred ratings, related requirements and application recommendations for LV power circuit breakers and a.c. power circuit protectors.
ANSI/IEEE-C37.20.1/2002	Metal enclosed low voltage power circuit breaker switchgear.
ANSI/IEEE-C37.20.2/1999	Metal clad and station type cubicle switchgear.
ANSI/IEEE-C37.20.3/2001	Metal enclosed interrupter switchgear.
ANSI/IEEE-C37.21/1998	Standard for control switchboards.
ANSI/IEEE-C37.23/1992	Guide for calculating losses in isolated phase bus.
ANSI-C37.47/1992	Specifications for distribution fuse disconnecting switches, fuse supports and current limiting fuses.
ANSI-C84.1/1995	Electric power systems and equipment – Voltage ratings (60 Hz).
NEMA/ICS-1/2001	Industrial controls and systems. General requirements.
NEMA/ICS-2/2000	Industrial control and systems, controllers, contactors and overload relays, rated not more than 2000 V a.c. or 750 V d.c.
NEMA/ICS-2.3/1995	Instructions for the handling, installation, operation and maintenance of MCCs.
NEMA/ICS-3/1993	Industrial control and systems. Factory built assemblies.
NEMA/ICS-6/2001	Industrial control and systems. Enclosures.
NEMA/PB-1/2000	Panel boards.
NEMA/PB-1.1/2002	General instructions for proper installation, operation and maintenance of panel boards, rated 600 V or less.
NEMA/PB-2/2002	Dead front distribution switchboards.
NEMA/SG-6/2000	Power switching equipment.
NEMA/WC-57/2004	Control, thermo-couple extension and instrumentation cables.

Notes

1 In the table of relevant Standards while the latest editions of the Standards are provided, it is possible that revised editions have become available or some of them are even withdrawn. With the advances in technology and/or its application, the upgrading of Standards is a continuous process by different Standards organizations. It is therefore advisable that for more authentic references, one may consult the relevant organizations for the latest version of a Standard.

2 Some of the BS or IS Standards mentioned against IEC may not be identical.

3 The year noted against each Standard may also refer to the year it was last reaffirmed and not necessarily the year of publication.

List of formulae used

Selection of bases

$$\text{Per unit quantity, p.u.} = \frac{\text{Actual quantity}}{\text{Chosen base}} \quad (13.1)$$

Actual impedance

$$Z_1 = \frac{V^2}{\text{kVA} \times 1000}\ \Omega \quad (13.2)$$

If z_p is the p.u. impedance then

$$z_p = \frac{Z_1 \cdot (\text{base kVA}) \times 1000}{\text{Base } V^2} \quad (13.3)$$

$$z_{p2} = z_{p1}\left(\frac{V_1^2}{\text{kVA}_1} \times \frac{\text{kVA}_2}{V_2^2}\right) \quad (13.4)$$

z_{p1} = p.u. impedance at the original base, and

z_{p2} = p.u. impedance at the new base

Fault current

$$I_{sc} = \frac{I_r}{z_p} \text{ i.e. } \frac{\text{Rated current}}{\text{Transient unit impedance}} \quad (13.5)$$

$$\text{Fault MVA} = \frac{\text{Base MVA}}{z_p} \text{ etc.} \quad (13.6)$$

Further Reading

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4. Lythall, R.T., *The J & P Switchgear Book,* Butterworths.
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Appendix

Painting procedure of switchgear and controlgear assemblies and treatment of effluent

Contents

A13.1 Introduction

Painting of all metallic surfaces of a switchgear or a controlgear assembly or a bus system is an essential requirement of IEC, IEEE, ANSI and all national and international Standards related to such assemblies to provide them with an aesthetic appearance, and prevent from rust and corrosion. Painting serves these purposes by providing the machine with a hard and longer-lasting metallic surface. We describe briefly, the basic procedure to paint and test painted surfaces. In the discussion, we have laid more emphasis on MS sheet-metal surfaces as these are more typical.

The painting procedure for other metal surfaces, although similar, the process of pre-treatment for cast iron components or non-ferrous metals, such as aluminium and copper, may need more care. The process of pre-treatment in such cases may vary slightly than for MS, as noted below. Such surfaces may require a change in the type of chemicals, their concentration and duration of treatment. The final surface preparation and painting procedure, however, will remain the same for all.

The total painting procedure, may be divided into the following operations:

1 Sheet pre-treatment (phosphate coating)
2 Preparing the surface
3 Applying the final paint
4 Curing the paint
5 Testing the painted surfaces
6 Providing a peelable coating compound, if necessary and
7 Effluent treatment and discharge of waste water.

A13.2 Sheet pre-treatment (phosphate coating)

In Table A13.1 we describe the most common practices being adopted to pre-treat and phosphate coat ferrous and non-ferrous surfaces, before applying paint:

Degreasing and cleaning

Degreasing is a process to remove oil, grease, dirt and swarf (file dust) etc. from a surface.

Types of cleaners (degreasing agents)
There are several types of cleaners available for this purpose, for example:

1 **Alkaline cleaners (caustic based)** These are caustic soda based and are suitable for ferrous metals only. They are more effective in removing greases of vegetable oils, rather than mineral (petroleum) oils, as they do not saponify the mineral oils.
2 **Neutral cleaners (non-caustic based)** These are ethylene oxide condensates, and easily emulsify the mineral oils and greases. They are more useful for

Table A13.1 Process of sheet pre-treatment (phosphate coating)

Pre-treatment process	*For ferrous metals*			*For non-ferrous metals*
	Heavily scaled and heavily rusted surfaces (hot-rolled sheets)	*Heavily scaled, but mildly rusted-surfaces (hot-rolled sheets)*	*Mildly scaled and mildly rusted surfaces (cold-rolled sheets)*	
1 Degreasing and cleaning	✓	✓	✓	✓
1 Water rinsing	✓	✓	✓	✓
3 Descaling or acid pickling	✓	✓	–	–
4 Water rinsing	✓	✓	–	–
5 De-rusting	✓	–	✓[a]	–
6 Water rinsing	✓	Second water rinsing or neutralizing is recommended, in HCl pickling	✓[a]	–
7 Zinc phosphating[b]	✓	✓	✓	✓
8 Water rinsing	✓	✓	✓	✓
9. Passivation[b]	✓	✓	✓	✓
No. of tanks	Nine-tank method	Eight-tank method	Seven-tank method	Five-tank method

[a]Instead of de-rusting, a pickling process may also be sufficient, depending upon the surface condition of the sheets.
[b]After the pickling process, if the phosphating bath contains traces of sulphate (SO_4) or chloride (Cl) salts, the phosphated surface may become highly hygroscopic, and absorb atmospheric moisture through even a very well painted surface, and show rusting with passage of time (depending upon the atmospheric conditions at the place of installation). To avoid this and to achieve a long life for all painted surfaces, it is recommended that all these salts are first neutralized. This is possible with the use of de-mineralized (DM) water, at least for the make-up baths of phosphating and passivation. Where water is heavy and contains mineral salts, a small DM unit can be installed. It is an inexpensive procedure for the quality of phosphate coating that would be achieved. This will also enhance the working life of these bath solutions, and economize on their consumption. De-mineralization means removal of all sulphate (SO_4) and chloride (Cl) salts.

Note
The transfer of jobs from one tank to another may be done by an overhead travelling hoist to handle bulky and heavy objects.

sheet-metal components, which contain no lead compound lubricants (as used for deep-drawing operations), and are also suitable for non-ferrous metals. These cleaners emulsify faster than other types and are more suitable for heavy production lines.

3 **Emulsion cleaners** These are emulsified chlorinated solvents and are kerosene based, suitable for mineral oils (petroleum and heavy petroleum greases) and deep-drawn components, using lead compounds as lubricants. They are also suitable for non-ferrous metals.

4 **Solvent cleaners** These are tri-chloro ethylene (TCE) and are highly evaporating cleaners, possessing toxic properties. Their application is the same as for neutral cleaners.

Concentration, bath temperature and dipping time
These are indicated in Table A13.2.

Tank material

A mild-steel (MS) tank with wall thickness of 4–6 mm, with a heating arrangement and a thermostat temperature control, will be ideal for this purpose. Even when a cold process is adopted, heating will be imperative during winter or in cold climates, where the bath temperature would be less than 40°C. A protective lining inside the tank is generally not essential, as the chemical does not attack the metal. An anti-corrosive paint, such as epoxy or polyurethane may, however, be provided to enhance the life of the tank. The thermostat and heater may be of stainless steel or ordinary water heaters. The tank may be made slanting ($^1/_2$ inch in an 8-feet length is adequate) to have an over-flow system to remove the oil and grease scum during the degreasing process.

Checking the bath concentration

The concentration of bath solution in caustic-based cleaners can be checked by a simple titration method as noted below, while for the remaining types of cleaners, a visual check of the degreased surfaces will be sufficient. The titration method is as follows:

Table A13.2 Concentration, bath temperature and dipping time

Type of cleaner	*Concentration*	*Bath temperature*	*Dipping time*
Alkaline cleaners	3–5% by weight or volume of bath	90–95°C	10–15 min
Neutral cleaners	3–5% by weight or volume of bath	(i) 50–70°C (ii) Also possible at room temp. (40–45°C)	3–5 min 10–15 min
Emulsion cleaners	No dilution	50–60°C	3–5 min
Solvent cleaners	No dilution	80°C	3–5 min

Note
The exact values will depend upon the surface condition of the material and the field experience and skill of the operator. For more accurate details consult the chemical manufacturer.

- Pipette out 10 ml of bath solution and add 90 ml of distilled water (total 100 ml).
- Remove 10 ml of this solution and add a few (three to five) drops of phenol phthalein and shake.
- Titrate this against N/10-HCl solution until the colour changes to pink.
- A burette reading will indicate the actual pointage of the bath compared to the standard (approximately 3–6) for a concentration of 3–5%. Obtain the standard pointage from the chemical manufacturer.

For each one point of lower strength, add 1 litre of chemical per 100 litre of bath.

Note
N/10-ready-made laboratory chemicals are easily available.

Precautions to be observed

1 When making a fresh bath, stir the chemical well in a separate container, preferably in hot water, before mixing it into the tank.
2 Skim off oil and grease scum from the surface of the bath every day or more frequently, depending upon the amount of work being handled.
3 When using alkali base cleaners, protect the eyes and skin from direct contact with the chemical.

Water rinsing

To rinse, wash the surface in clear, continuous running water to remove all traces of degreasing agent from the surface. Two/three dips at room temperature are sufficient.

An MS tank with a wall thickness of 3–4 mm is adequate, otherwise the thickness can be similar to that for the degreasing tank but without the heating arrangement. It may also be coated with an anti-corrosive paint to enhance its life.

Carry out the rinsing before the chemical dries on the surface.

De-scaling or acid pickling

This is a process to remove heavy black scale and rust from the surface. Hot-rolled sheets that may have such scale formation need only be acid pickled. Cold-rolled sheets, which may carry no such scales, need not be acid pickled. Depending upon the type of surface, one of the following methods may be adopted.

For heavily scaled and heavily rusted surfaces

1 **Acid pickling** This can be done under the following operating conditions, either with sulphuric acid (H_2SO_4), or hydrochloric acid (HCl). H_2SO_4 releases a lot of fumes and is ineffective under cold conditions. It forms iron sulphate, which forms a hard deposit at the bottom of the tank and is difficult to remove (Table A13.2(a)).

2 **Tank material** A mild-steel (MS) tank, with a wall thickness of 4–6 mm, and having an acid-proof lining of FRP (fibre-reinforced plastic), rubber or PVC will be suitable for this purpose. A heating arrangement, even if a cold process is adopted, will be ideal for

winters and cold climates. The heaters and thermostat must have a stainless steel body.

3 **Checking bath concentration** Acid content can be checked with the help of a pH paper. If this indicates more than 3.5, add more acid to make it less than this reading.

4 **Precautions**

- At lower concentration or lower bath temperature, the acid will attack slowly on scale and rust will take longer to pickle. Therefore, monitor concentration and bath temperature.
- H_2SO_4 reacts with water and generates heat. When using this chemical, pour it slowly into the water.
- Acid fumes, being heavy, will vaporize over the tanks. They must be vented quickly to the atmosphere through an exhaust on the pickling tank otherwise the completed phosphate surfaces may be adversely affected. Apparently, the surfaces may not show rusting immediately, but may develop it while the equipment is in service.

5 **Water rinsing** To rinse, wash the surface in clear, continuously running water to remove all traces of acid from the surface. Two or three dips at room temperature will be sufficient. The details of tank will be similar to those for the acid tank but without any heating arrangement.

6 **De-rusting** This is a process to remove rust from the surface. The procedure of de-rusting is given in Table A13.3, column 2. The de-rusting chemical is phosphoric acid based, and does not contaminate the phosphating tank.

7 **Tank material** A mild-steel (MS) tank with a wall thickness of 4–6 mm having a heating arrangement and a thermostat temperature control will be required. Since the phosphoric acid-based, rust solvent is corrosion resistant, no tank lining is necessary. The heaters and thermostat may be of stainless steel or lead-covered for better durability.

Table A13.2(a) Pickling process in heavily scaled and heavily rusted surfaces

Parameters	H_2SO_4	HCl
Concentration (by weight)	25%	30–50%
Bath temperature	60 ± 5°C	40–45°C
Approximate time of pickling	15–20 min.	15–20 min.
Inhibitor: since the acid attacks the metal and causes pitting, an inhibitor must be added	0.25–0.5% by weight	0.25–0.5% by weight

Notes

1 Concentration of acid and time of pickling will depend upon the condition of the surface and the bath temperature.

2 One or two dips during the course of pickling will give better results and enhance the efficiency of the process, as it will quickly remove loose scales.

3 To reduce metal attack and fumes, use an acid inhibitor during acid pickling. A 0.01% concentration is recommended.

8 **Water rinsing** To rinse, wash the surface in clear water an MS tank with a thickness of 3–4 mm is adequate. It may, however, be provided with corrosion-resistant paint to extend its life.

Heavily scaled but mildly rusted surfaces

The process is similar to the above, except that de-rusting and water rinsing tanks can now be eliminated if H_2SO_4 is used for the pickling. But when HCl is used, the second water rinsing tank should be retained, to remove all traces of HCl thoroughly before it enters the phosphating tank. Otherwise the trapped traces of HCl (chloride contents) will contaminate the phosphating bath and adversely affect the phosphate coating. This may be shown by rusting, not immediately but in the course of time. It may be noted that traces of chloride are not removed so easily and hence the need for a second rinsing[a].

In place of simple water rinsing, it is more appropriate to add a neutralizing agent such as hexa-amine or sodium nitrite ($NaNO_2$) to make a bath of 3–4% concentration. In the bath, the job may be dipped for two or three minutes at room temperature to neutralize all the trapped traces of acid. This method also helps to accelerate the process of phosphating when the job is transferred to the phosphating tank. The concentration of bath solution can be checked along similar lines to those for the toner used in the phosphating tank.

The tank will be similar to the first rinsing tank. It is recommended that the rinsing be done at an elevated temperature of, say, 60–70°C, even when HCl pickling is carried out in cold conditions to agitate the air and easily remove all traces of chloride.

The bath water may be checked for any acid traces with the help of a pH paper. This should give a reading above 6, preferably around 7.

[a] *Note*

When de-rusting is adopted after HCl pickling, the second water rinsing, as recommended above, is not essential as the traces of chloride, if any, will be neutralized in the de-rusting tank, which is a phosphoric acid-based rust solvent.

Mildly scaled and mildly rusted surfaces

Now the process of acid pickling may be eliminated if desired. Instead, only the de-rusting process can be used, as indicated in column 2 of Table A13.3. Alternatively acid pickling may be carried out as before, but at a lower concentration and temperature, as noted in column 1. Since one cannot always be certain of the quality of sheet surfaces it is advisable to follow the process of acid pickling.

Sand blasting

The scale can also be removed by shot blasting using abrasive grits such as dry sand, less than 1 mm ϕ. This method is more suited for components not suited to the dip method and cast iron components, in which the acid may become trapped in the porous surfaces. For sheet-metal components and complicated shapes and crevices, the dip method alone is recommended.

Table A13.3 Pickling and de-rusting process in mildly scaled and mildly rusted surfaces

Description	*Pickling-cum-de-rusting tank (Hot-rolled or cold-rolled sheets with mild scaling and rust)* 1		*De-rusting tank (phosphoric acid-based rust solvent)* 2	
			Heating type solvent	*Cold type solvent*
	H_2SO_4	HCl	*Hot-rolled sheets with mild scaling*	*Cold-rolled sheets*
Concentration (by weight)	10–15%	25–30%	15–20%	15–20%
Temperature	60 ± 5°C	40–45°C	60–70°C (Max. 80°C)	40–45°C
Approx. time of pickling and de-rusting	5–10 min.	10–15 Min.	10–15 min.	3–5 min.
Inhibitor	0.25–0.5% by weight	0.25–0.5% by weight	Not required	
Checking the concentration	By pH paper: should not be more than 3.5		[a]See footnote	
Water rinsing	Only one water rinsing, with a few extra dips, is adequate		As noted at Sr. No. 8 on previous page.	

[a] The phosphoric acid-based solvent used for de-rusting can be checked as for degreasing but titration will now be carried out against an N/10 NaOH solution until the colour changes to green. A burette reading will indicate the actual pointage of the bath compared to the standard (almost 4 for a concentration of 5% and 16 for a concentration of 20%). Obtain the standard pointage from the chemical manufacturer. For each one point lower strength, add 1.2 ℓ of solvent per 100 ℓ of bath.

Phosphating

Process

This is a process to provide a fine coat of zinc phosphate or zinc calcium phosphate on ferrous and non-ferrous surfaces. It is a highly corrosion-resistant bonding to protect the surfaces from corrosion and rust. The rust may creep under the painted or scratched surfaces and crevices. This is a phosphate base chemical and can be applied cold or hot. However, the cold process is not recommended, as it may give a coat of about 3–5 g/m^2 whereas for the equipment being discussed the coat must be above 5 g/m^2.

Concentration:

- Hot process – 3–5% by volume of bath
- Cold process – 10–15% by volume of bath

Toner, accelerator or oxidizing agent

This is alkaline in nature, say, of sodium nitrite ($NaNO_2$) base and may be added to accelerate the process. At a very high temperature, however, above 70°C, it becomes ineffective. The bath temperature must therefore be kept below this.

Concentration:

250–300g/1000 ℓ of bath volume.

where the phosphate coating is required to be more than 5 g/m^2 an extra hot process is used, as noted later, when the use of toner (accelerator) becomes redundant, as it is ineffective above 70°C.

Bath temperature and approximate time of dipping

1 For the accelerated process:
   For a normal coating:
   - Hot process: 60–70°C for 2–5 minutes will provide a phosphate coating of up to 5 g/m^2.
   - Cold process: 40–45°C for 20–25 minutes will provide a phosphate coating of up to 3–3.5 g/m^2.

2 For the unaccelerated process:
   For a heavy coating:
   Hot process: 80–90°C for 5–7 minutes will provide a phosphate coating of more than 5 g/m^2.

Material

An MS tank with a wall thickness of 3–4 mm, having a heating arrangement and a thermostat temperature control will be required. No protective lining is necessary as the phosphate coating itself is protective.

Checking the concentration of the bath

Carry this out as below.

- Pipette out 10 ml of bath solution.
- Add a few drops of methyl orange indicator and shake.
- Titrate it against an N/10 NaOH solution until the colour changes to yellow.
- Note the addition of NaOH, which will indicate free acidity.
- To the same solution add a few drops of *phenol* phthalein, and titrate it against N/10 NaOH until a pink colour appears, which will indicate the total acidity of the bath. This is approximately 35 to 37 for a concentration of 5% for a hot process and 60 to 64 for a concentration of 10% for a cold process. Obtain the standard total acidity of the hot or cold process chemicals from the manufacturer.
- For each one-point lower strength, add 125 to 150 ml

chemical per 100 ℓ of bath. Consult the manufacturer for the exact details.

Checking the toner

- By starch iodide paper (original colour white)
- Dip a piece of this paper into the bath solution for a few seconds.
- The change of colour of the paper will indicate the condition of the toner, i.e.
  White – no toner
  Pale mauve (light blue) – insufficient toner
  Blue or dark blue – correct quantity of toner
  Black – excess toner.

Precautions

1 The phosphated surface must be transferred to the water rinsing tank without delay.
2 To protect the surface from contamination by foreign matter, it should not be touched, wetted or subject to condensation.
3 The sludge of the phosphate bath that settles at the bottom, must be cleaned as frequently as possible. The clear solution from the surface can be siphoned into an empty rinsing tank. After cleaning the tank, the clear solution can be poured back into the tank.
4 The phosphate solution is acidic. Continuous human contact or splashing of bath solution must be avoided, and hands or skin washed clean with a dilute solution of 1–2% of ammonium bicarbonate.

Water rinsing

To rinse, wash the surface in clear, continuous running water to remove all traces of soluble salts which may cause blistering on the surface. The tank can be similar to the phosphating tank. It may, however, be coated with an anti-corrosive paint to extend its life.

Passivation

This is the final neutralizing rinse after the pre-treatment to obtain a better corrosion resistance. The phosphated surfaces are treated with chromic acid-based or acidified sodium dichromate solutions which are not affected by moisture and thus protect the phosphate coating.

Concentration:

- Hot process – 125–150 g/1000 ℓ of bath volume
- Cold process – 250–500 g/1000 ℓ of bath volume

A very high content of this acidic solution may dissolve the phosphate coating.

Bath temperature and approximate dipping time

- Hot process – 60–70°C for 30–45 seconds
- The hot process is generally not recommended as it may dissolve the phosphate coating
- Cold process – 40–45°C for 60 seconds or so.

Tank for passivation

This is similar to that for phosphating. It may, however, be coated with an anti-corrosive paint to extend its life.

Checking the bath concentration

This can be done by checking the pH value of the bath solution.

- Use a universal pH paper. The pH value should be between 2 and 3.
- If the value exceeds 3, add more chemical.
- If it is less than 2, drain a part of the bath and replenish it with fresh water.

Drying

It is essential to dry passivated surfaces promptly to protect them from moisture and atmospheric contamination. The drying may be carried out by blowing compressed air, which is easier and more economical, or by placing in the same oven as for the paint. Special care need be taken with hidden surfaces, such as in corners, bends and crevices, to ensure that there is no trapped moisture.

Sealing

The phosphate coating itself is not protective unless sealed with a protective coating of primer. Sealing is therefore carried out by applying a coat of primer within 12 hours of phosphating, if the atmosphere is dry, or immediately if it is humid. Otherwise the atmospheric humidity may react with the surface and form a film of rust (i.e. ferric oxide (Fe_2O_3)).

Notes

1 The chemical concentrations, bath temperature and process times noted above are only indicative and for general reference. They may vary with the type of chemicals, the manufacturer and the condition of the surface to be treated. Details may be obtained from the chemical manufacturer to formulate the internal sheet treatment process guidelines.
2 It is strongly recommended to check the concentration of all the baths every day before commencing work. A passivation solution particularly, must be changed frequently, rather than adding more chemical to the same bath, depending upon the amount of work every day.

A13.3 Pre-treatment of non-ferrous components

1 Degreasing – with neutral or non-caustic based chemical, otherwise same as for ferrous metals.
2 Pickling and de-rusting – Not necessary, as there is no scale formation or rust on the non-ferrous surfaces.
3 The rest of the process is almost the same as for ferrous components.

A13.4 Size of tanks

These should be suitable to accommodate the size and volume of a switchgear or a controlgear assembly being manufactured by the unit. The size noted below should be adequate to meet most needs:

Table A13.4 Priming the treated surfaces

	Description	Air drying 1	Air drying-cum-stoving 2	Stoving 3
1	Purpose	(i) To provide protection to the treated surfaces by sealing (ii) To provide an adhesive surface for the final paint (iii) To smoothe the surface		
2	Types of primers	(i) For synthetic paints, zinc-chromate primers are recommended, which contain zinc chromate pigments and are highly corrosion resistant (ii) For epoxy paints, epoxy primers must be used		
3	Preparation	(i) Remove the skin from the surface of the primer, if any, and stir well the contents of the drum to make it a homogenous mixture (ii) Filter the mixture through a cambric cloth		
4	To adjust the viscosity by a Ford Cup Viscometer No. 4	21–25 seconds (as for synthetic and epoxy primers)	21–25 seconds	21–25 seconds
5	Solvent (thinner): (i) For synthetic primers (ii) For epoxy primers	 General purpose Epoxy	 Stoving Epoxy	 Stoving Epoxy
6	Thickness of one coat: (i) Synthetic primers (ii) Epoxy primers	 25–30 microns 35–50 microns	 25–30 microns 35–50 microns	 25–30 microns 35–50 microns
		Note: To provide a coat up to these thicknesses, a one-coat two-pass will be sufficient. Each coat will generally mean one spray horizontally and one vertically, on both sides of the job		
7.	Air pressure	3–3.5 kg/cm^2 (40–50 lb/in^2). Air must be dry and free from oil and grease		
8	Curing temperature: (i) For synthetic primers (ii) For epoxy primers (a) Air drying (b) Epoxy ester	 Room temperature[a] Room temperature[a] –	 (i) Room temperature[a] or (ii) 100–120°C (i) Room temperature[a] or (ii) 60–80°C	 120–130°C (Maximum 140°C) Not recommended[b] 140–150°C
9	Curing time (i) For synthetic primers (ii) For epoxy primers (a) Air drying (b) Epoxy ester	 2 hours surface dry, 12–16 hours hard dry 2 hours surface dry, 12–16 hours hard dry –	 (i) 12–16 hours at room temperature (ii) 20–30 minutes at 100–120°C (i) 12–16 hours at room temperature (ii) 20–30 minutes at 60–80°C –	 20–30 minutes – 30–40 minutes
10	Surface fillers (putty)[c]	Air drying	Air drying or stoving ← (synthetic or epoxy, as the case may be) →	Stoving
11	Final surface making	Rub the putty, if applied, with water and slightly coarse emery paper No. 180–220. It is better to rub the surface, even when no putty is applied to provide the surface with a knurling effect, to have a better adhesive surface for the paint.		

[a] Room temperature is considered to be around 40–45°C. In winter or for cold climates, where the room temperature may be less than this, suitable heating arrangements must be provided to obtain the desired results.
[b] Air-drying epoxy paints are not required to be stoved due to chemical reaction at about 120°C, which may affect its hardness. To speed up the curing, it may be stoved at a maximum temperature of, say, 60–80°C as noted in column 2.
[c] As discussed earlier, putty filling is generally not advisable unless the surface is poor, uneven or has pin holes. It is advisable to use primer surfacer, which provides a thicker coat and helps to fill such surfaces. The epoxy primer is thicker and may do this job in most cases.

Length – 3 m
Width – 1 m
Depth – 1.2 m
The size, however, should be commensurate with the size of the assemblies and the scale of work.

Automation

The entire sheet pre-treatment process described above can also be made automatic as noted below:

- Set each thermostat at the required temperature whenever heaters are provided.
- Define the process time of each operation and set the hoist to dip, lift and carry the job to the next tank etc.

A13.5 Procedure for liquid painting

Making the surface

Within 12 hours of surface pre-treatment the surface must be sealed through a coat of primer as described in Table A13.4. After the primer coat, the surface must be air dried or stoved. The stoving method is always preferred, being faster and neater, compared to an air-drying process, which takes longer to set, and the painted surfaces may collect suspended dust particles from the atmosphere. After the primer is set, the surface may be applied, if required, with a very thin coat of putty to fill in any pin holes or other irregularities. The putty is also air dried or stoved and then rubbed gently with emery paper and washed with water to obtain a smooth plane surface, ready to be coated with the final paint. In fact, putty filling is not recommended because it is wasteful. It also adversely affects the strength of the paint film and increases porosity on the surface, and should be avoided as far as possible. It may not be necessary when cold-rolled sheets are used for fabrication.

A13.6 Applying the final coat of paint

After the surface has been prepared, the final coat of paint is applied. The brief procedure for painting is almost the same as for the primer and described in Table A13.4.

It is recommended to apply the primer or paint inside a spray booth, which would offer the following advantages:

- **Conventional method using a spray booth (wet method)** This traps the primer and the paint fumes, after routing them through a curtain of water, and then exhausts them into the atmosphere. This procedure, therefore, causes no environmental pollution. Within the plant area it also protects the operator and others from a health hazard. It also protects machinery installed nearby from paint fumes and also the plant from a fire hazard. The waste water, after treatment and neutralization, is discharged into the drains. To achieve this, the spray booth is provided with blowers on the top having its suction through a trough of water. (Refer to Figure A13.1, illustrating this arrangement.) It serves a dual purpose: first, it creates a draught of air within the booth to help eliminate all the paint fumes and second, it produces a curtain of water to dissolve all over-sprayed paint. The dissolved paint can then be collected at the bottom in a trough and disposed of, and the trough-contaminated water can be drained out after neutralization and effluent treatment. Figure A13.1 illustrates a typical layout of a medium-sized paint shop.
- **Electrostatic method** This is also a wet method like the conventional process, except that the paint is now electrostatically charged, similar to the powder paint in a dry method as discussed later. The paint, being highly charged electrostatically, is wrapped around the object automatically.

Liquid paint

These paints are resin based and the paints required for sheet-metal surfaces are generally alkyd-based resins. For general industrial applications, any of the following types of enamel paints may be used,

- Air drying
- Air drying-cum-stoving
- Stoving

For special applications, however, such as for normally humid areas, and contaminated or chemically aggressive locations, epoxy paints are considered to be more appropriate. They provide a protective coating which is resistant to chemical fumes, corrosion and temperature. Chlorinated rubber paints, which also fall into the same category of protective paints, may also be used for these areas but, not being temperature resistant, are not preferred to epoxy paints.

Preparation of paint, its viscosity, solvent, thickness of one coat, air pressure, curing temperature and time of curing will remain the same as for the primer (Table A13.4).

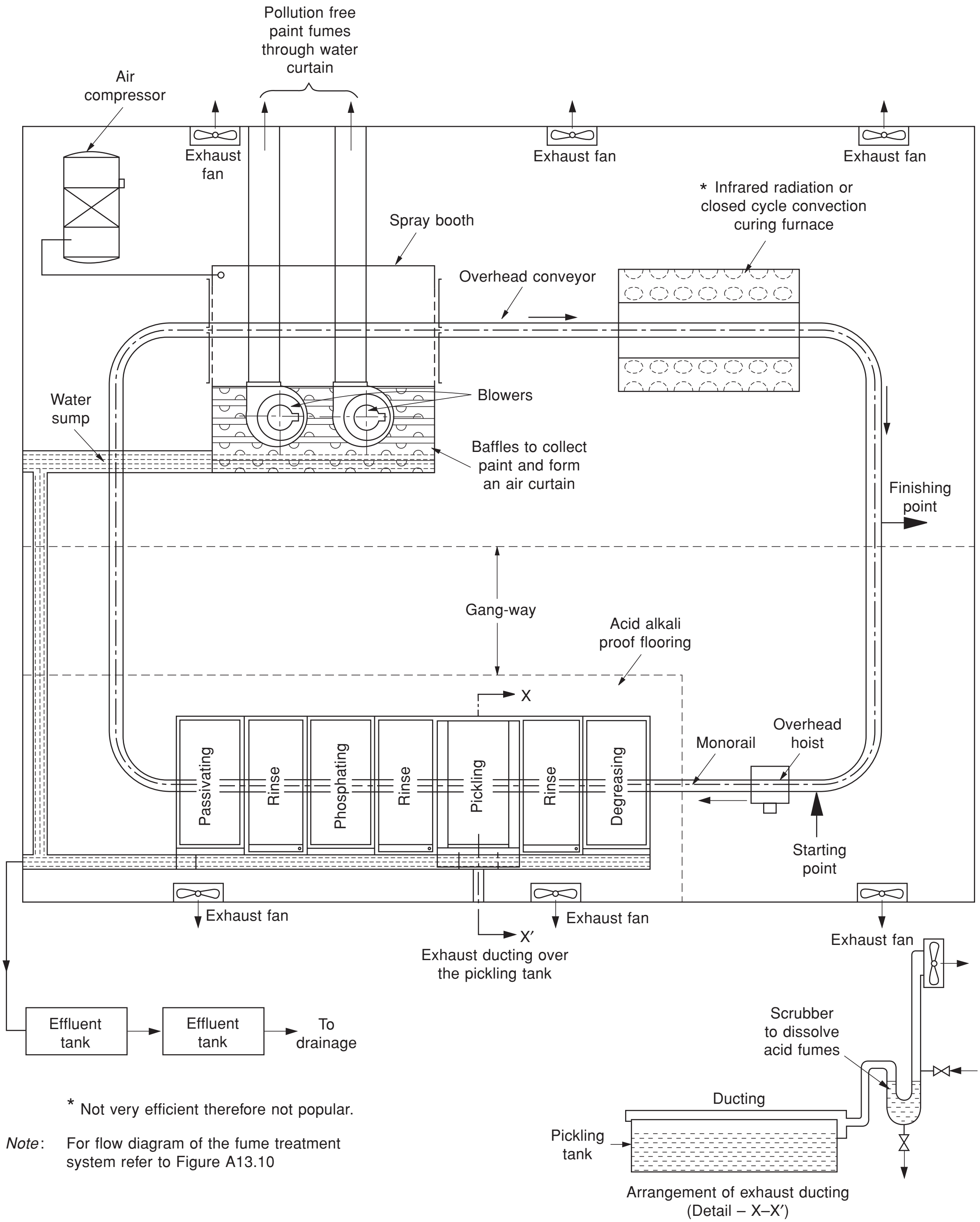
Important notes on Table A13.4 and procedure for painting

1 Thickness of coat:

- The recommended thickness of the total coat (primer plus paint) will depend upon the site conditions. For a normally clean environment, a coat of up to 50 microns is considered adequate. For a dusty or humid location requiring constant servicing and cleaning, a thicker coat, say, up to 70–80 microns, is considered to be adequate.
- A thickness of up to 50 microns is possible through one coat of primer and paint. To obtain a greater thickness an additional coat of paint, rather than primer, may be applied after almost curing the first coat. A thickness of primer of more than 30 microns is not considered satisfactory as it may diminish its adhesive properties. To obtain a thickness of up to 100 microns, for instance, one coat of primer and two coats of paint may be sufficient. Each coat being around 30–35 microns.
- Whenever a second coat of paint is required for better adhesion of paint, it is better to rub the painted surface of the first coat with a finer emery paper (No. 300 to 400) and then to wash and dry it before applying the second coat.
- For protective coatings, such as with epoxy paints, the minimum thickness of paint (primer plus paint) should be around 70–80 microns, which is also possible through one coat each of primer and paint.

2 If different paint shades are required on outer and inner surfaces paint any one side first, cure it almost completely and then apply the second shade on the other side. Even when there is a wrapping on the second side, it can be easily wiped and cleaned, without affecting the first.

3 The temperature and time of curing, as indicated in Table A13.4, are indicative and for general guidance only. They may vary with the type and quality of paint and effectiveness of the furnace. For exact details, consult the paint manufacturer. The operator may also vary the given parameters slightly, based on his own experience and the end results.



* Not very efficient therefore not popular.

Note: For flow diagram of the fume treatment system refer to Figure A13.10

Figure A13.1 A liquid painting system illustrating typical layout of a medium-sized paint shop showing a seven-tank pre-treatment process

4 Curing time will also depend upon the thickness of coat and the shape of the workpiece.
5 Air-drying paints are easily available as noted above but they may not suit a regular production line as:

- They would require a longer drying time (slow process), which a regular production line can ill afford.
- They would require a larger storage area, which should be dustproof but well ventilated to provide for sufficient air circulation.
- During the drying time, the workpiece may collect dust from suspended dust particles in the atmosphere.
- The air dried surfaces may not be as neat and hard as the stoved surfaces.

6 Stove curing is a rapid method and is obtained by baking the paint for a specific time in a furnace at a specific temperature. The temperature and time will depend upon the type of paint being used and its thickness, the shape of the workpiece and the effectiveness of the furnace. (Refer to Table A13.4.) The oven may be electric or oil-fired convection type, with an arrangement to circulate the hot air around the workpiece. The heaters or the furnace may be installed at the bottom of the enclosure to cause the hot air to circulate by natural or forced convection. The heat consumed is high in such cases, as the whole furnace and its parts are heated first, and only then can it heat the workpiece. The heating-up time will thus depend upon the weight and size of the job and also the size and effectiveness of the furnace, but the job is not influenced by any external factors, such as air draught or atmospheric dust.

An infra-red (IR) bulb-type oven, where the heating is caused by radiation, was earlier considered a more effective and energy-saving method compared to the convection type due to direct heating of the paint. There was no heat loss to heat the body of the furnace or the workpiece itself. The paint is baked at the surface only, without thoroughly heating the workpiece. Such furnaces may not be airtight, as they are made flexible to adjust the workpiece at the most effective distance from the bulbs to obtain the most effective heat radiation. Being adjustable they can also accommodate any size of job but they may be influenced by external factors, such as draughts and suspended dust particles which may collect on the surface of the workpiece. To save on heat loss and protect the job from atmospheric dirt, the radiation-type oven may be closed from all sides, as much as is practical. When closed, it will also conserve heat and reduce baking time. However, the influence of surrounding conditions and the draughts are found to be great deterrents to taking full advantage of radiation efficiency. The latest trend, therefore, is to use a closed-chamber, convection-type furnace (Figure A13.2). The use of glass-wool and thermocoal as interior insulation now makes it possible to require only a moderate heat for the interior of the furnace and to prevent any heat loss through the furnace's body. The furnace is now totally dust-free and such furnaces are thus highly energy efficient for curing paint.

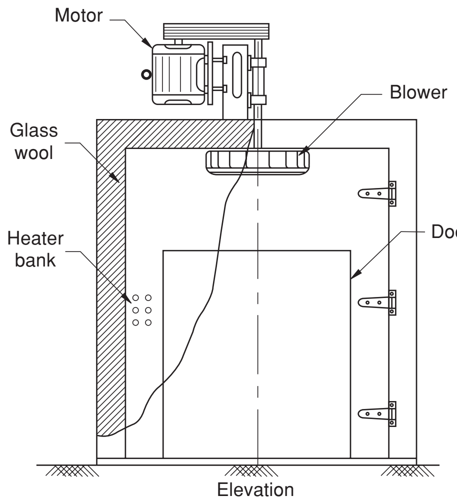


Figure A13.2 Closed-chamber convection-type furnace

Note
With the obvious advantages of powder paints, the latest practice is to opt for powder coating at most sheet metal paint shops, such as for motor housings, switchgear assemblies, bus systems and power capacitors, etc.

A13.7 Electrostatic technique of powder painting

In the previous section we discussed a more conventional type of painting process. A rather new (early 1960s) and more advanced technology is found in the electrostatic process of a powder coating system. This uses no liquids and no primer coat and can save on paint consumption by up to 50% compared to the conventional liquid paint method, due to an almost closed-loop painting process, incorporating a paint recovery and recycle system. It allows no paint fumes to the atmosphere, and causes no environmental pollution or fire hazard at the workplace. The technique is thus judged to be highly economical, besides being environment-friendly. It also ensures an absolutely uniform and perfect painted surface due to a uniform electrostatic field. Since the field is the same at all points of the metal surface, it attracts the charged powder paint particles with equal force and allows only as much paint at the surface as is actually required and for which the spray gun is set (i.e. the electrostatic field).

Principle of electrostatic technique

Similar electric charges repel and opposite electric charges attract each other. This is the principle on which the process of electrostatic spray painting is based. The paint particles are charged with a strong electrostatic field, which is created at the tip of the electrostatic spray gun, as a result of high potential difference between the tip of the gun and the object. The gun is maintained at a high negative potential with the help of a power pack unit, generating adjustable d.c. output, in the range of 0–100 kV, negative (Figures A13.3(a) and (b)). The variable potential difference is necessary to adjust the distance between the gun and the object and also maintain the paint thickness. Grounding may be performed by the hooks holding the workpiece. The highly charged paint is released through the gun at high pressure and is attracted by the oppositely charged object, to which it uniformly adheres. Both sides of the object may be painted at the same time.

Due to the diminishing strength of the electrostatic field, which will depend upon the thickness of the paint already coated, the spraying process provides a uniform coating on the entire surface. The process may even be made automatic through tracer guns, which may be set to move on a set pattern, like robots. For more details contact the manufacturers. This system may be more advantageous for industries that have jobs of a repetitive nature and in large quantities such as automobiles and home appliances.

Figure A13.3(a) Electrostatic spray gun with the power pack unit (Courtesy: Statfield)

Figure A13.3(b) Electrostatic gun

Powder paints

Powder paints are dry coating materials and are in the form of dry polymer powders. They are electrostatically charged and applied with force to the surface to be painted. On heating, they polymerize and form a tough film. A surface so produced will generally be better than the conventional wet lacquer paints, for obvious reasons. There are no solvents or thinners involved. The powder is made of resin hardeners, crosslinking components, pigments, extenders and additives etc. The blend is mixed in an extruder at a temperature of 100°C, cooled and granulated and sieved to separate out grits. This process causes no blisters on the surface. It is a single-coat process. In one pass a thickness of up to 60–70 microns can be obtained. The over-sprayed powder can be recovered and re-used.

Curing of paint

The paint is then cured in an oven. The curing time will depend upon the thickness of coat, shape of the workpiece and type of oven and its effectiveness. Generally, a coat of up to 60–70 microns at a stoving temperature of 180–200°C (depending upon the type of powder) should take around 10–12 minutes to cure. Contact the manufacturers for exact details.

Precautions to be observed

The storage and processing of powder paints must be carried out under well-controlled conditions. Powder paints should be stored at about 25°C. At higher temperatures they form into lumps.

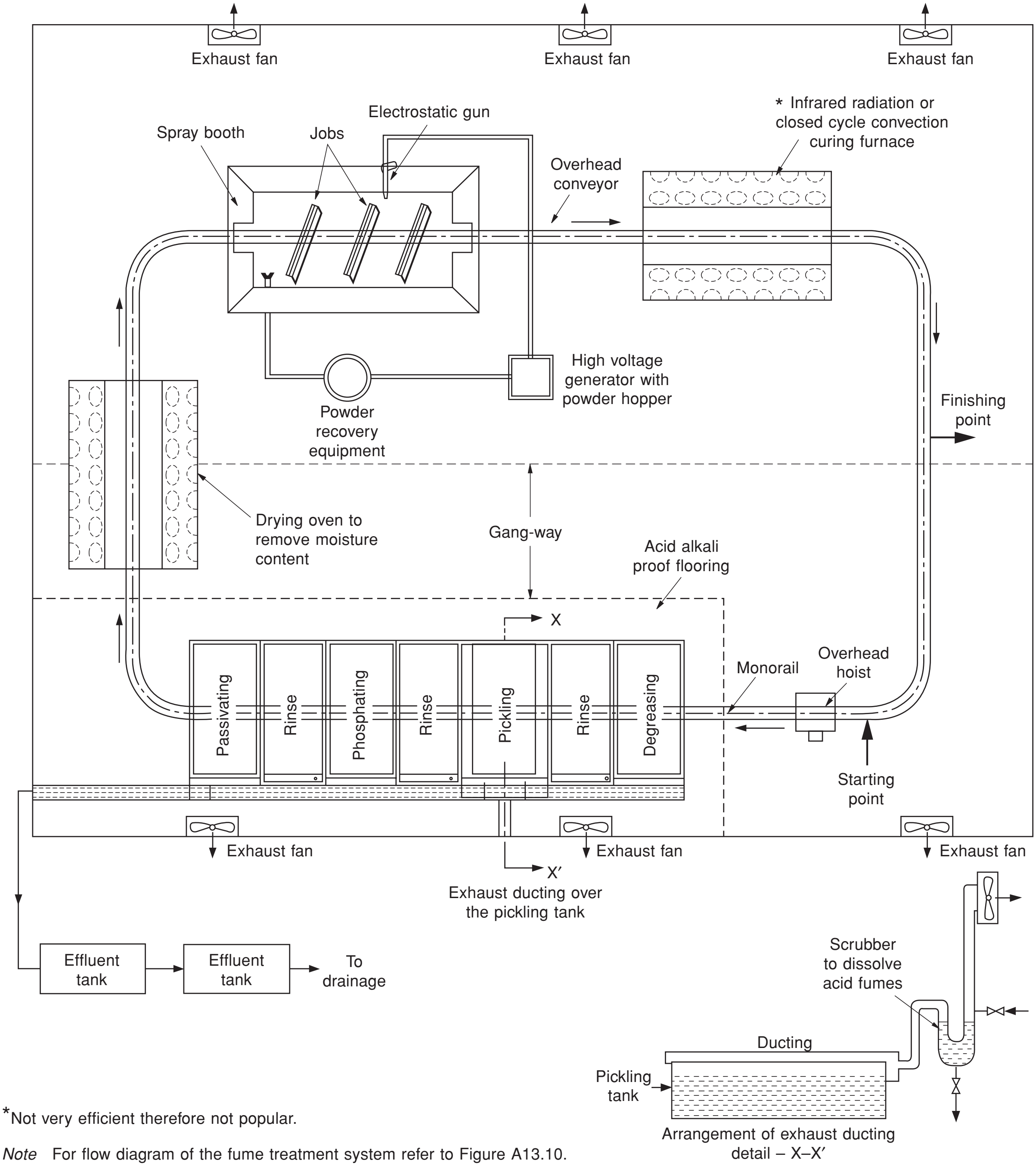
Equipment required

- Electrostatic gun, with built-in protection to cut off power when the gun is too close to the grounded workpiece.
- HV variable d.c. generator (0–100 kV negative) from a single-phase LV power source. The power required is around 60 W only.
- Power output and velocity controller to monitor control over quantity of powder and thickness of coat.
- Spray booth with paint recovery system.
- Oven.

Figure A13.4 shows a simple layout of a powder coating system with a powder recovery arrangement and Figure A13.5 its straight-line layout.

Limitations of powder coating

In an electrostatic technique, as a result of electrostatic charge, there is a wrapping effect and the paint also deposits at the edges of the other side of the workpiece. It is therefore advisable that the same shade be applied on both sides of the workpiece. While it is possible to apply different shades, this would be cumbersome and more time consuming. A lighter shade inside and a darker shade outside is sometimes required for a switchgear or a controlgear assembly. Although possible, this is not easily performed by this process. When two shades are



*Not very efficient therefore not popular.

Note For flow diagram of the fume treatment system refer to Figure A13.10.

Figure A13.4 A dry painting system illustrating typical layout of a medium-sized paint shop for powder painting showing a seven-tank pre-treatment process

required a more common practice is to paint one side (usually the outside) first with a powder coating and the other side may then be coated with the liquid paint.

This is satisfactory only for a totally folded construction. At welded joints, powder deposition will be less as a result of flux and carbon deposition. These deposits weaken the electrostatic field at such points and reduce the powder coating. However, in practice, it may not matter for it will hardly affect the coating by 5–10 microns or so, which may be immaterial in total service life. The most obvious disadvantage, however, is encountered when the painted surface is damaged or dented during transportation or installation etc., and is required to be repaired outdoors such as automobiles or switchgear assemblies at sites.

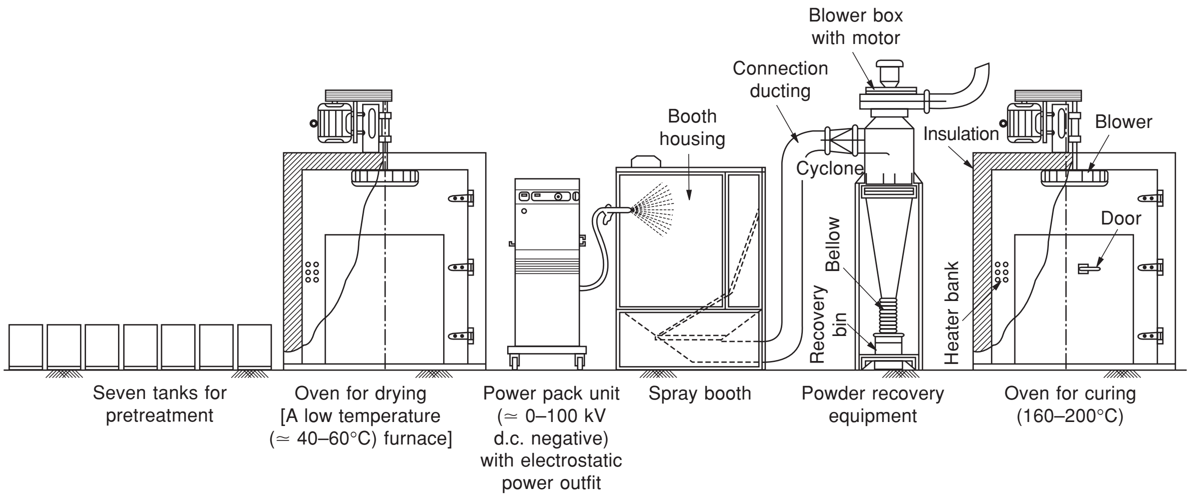


Figure A13.5 Single-line painting process for a powder system

Whenever the surface is damaged, the paint cracks, and it is difficult to be removed or touched up. Although it is possible to peel off the affected area with the help of special solvents, available from the manufacturers of such paints, the process of repairs outdoors is neither convenient nor provides a reliable finish. It is better to carry out repairs only at the plant.

These are a few disadvantages that have been deterrents in promoting this technique in all fields, the automotive segment particularly. Nevertheless, there is a willingness to adopt this technique, wherever possible, in view of its other inherent advantages, discussed earlier, particularly that of being environment-friendly. It is being used for all products where damage during transit or installation is rare such as household appliances, refrigerators, air conditioners, washing machines, etc. In the field of switchgear enclosures, this technique is also being gradually adopted by most manufacturers, as once they are installed, there is little chance of damage.

Harmony in paint shades

Presently the practice of many users of switchgear assemblies is to demand for different shades outside and inside. These shades may also vary from user to user. This indeed is cumbersome for the manufacturers to comply with as it calls for cleaning the booth every time a shade needs to be changed. It results in waste of paint, adds to pollution and causes loss of production. To ease on present painting exercise by the manufacturers and to save on paint and environment and to also bring harmony amongst manufacturers and their products worldwide it is suggestive to standardize only on a few shades for different voltages, types of industries and applications like indoor or outdoor, similar to colour coding of pipes in a chemical and fertilizer industry or in a hospital for carrying different types of fluids, liquid, gas or steam.

Similarly, the modern practice of providing CFL (compact fluorescent lamp) in place of GLS for control assemblies' internal lighting is a better illuminating source and coating the inside panel white may not be necessary. Same paint shade outside and inside the control assemblies will further relieve the manufacturers of extra painting process and cost.

A13.8 Testing of the painted surfaces

The following tests are generally recommended for testing the painted surfaces:

1 **Flexibility and adhesion test** This is conducted to check the flexibility of the coat. It can be carried out on a conical mandrel or on a folding apparatus as illustrated in Figure A13.6 (ISO 3205 and 3270) by bending the

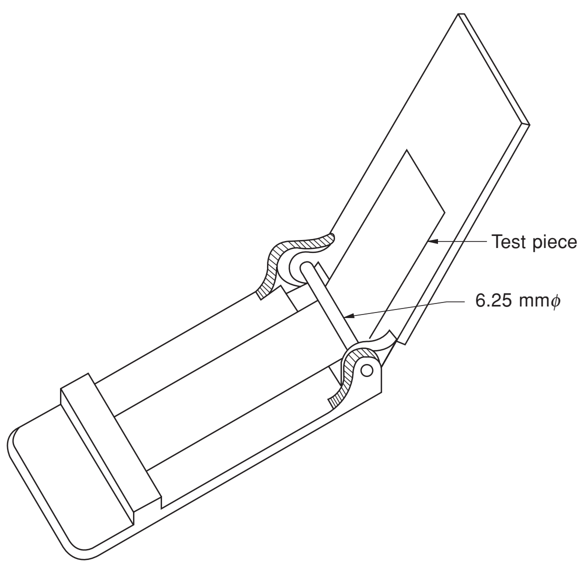


Figure A13.6 Apparatus for determining flexibility and adhesion test piece on it. The surface to be tested is kept on the outer side. The piece is bent through 180° (almost double folded) and examined for any cracks in the film. No cracks should develop.

2 **Stripping or hardness test** This is carried out to check the hardness of the painted surface and can be performed by a scratch hardness tester (ISO 3205 and 3270). A weighted tungsten-tipped needle is fixed at the far end of the test piece through a weight of 1 kg. The needle is then drawn at 30–40 m/s through its coated surface and the weight is increased up to 4 kg. After the test, the scratch so marked should not show up the bare metal surface. Figure A13.7 illustrates the test arrangement.

A simpler method would be using scratching knives and making small squares in the surface (minimum 100) around 1 mm^2 for primer and 2 mm^2 for the final surface and applying adhesive cellophane tape 25.4 mm wide, with an adhesion strength of 40 ± 2.8 g/mm then pulling it off suddenly. Not more than 5% of the squares must peel off.

3 **Thickness of coat** This can be checked by a magnetic coating thickness tester gauge (Figure A13.8)

4 **Gloss** Gloss meters may be used to measure the specular gloss of the paint.

5 **Shade** This may be checked visually with the help of a standard shade card.

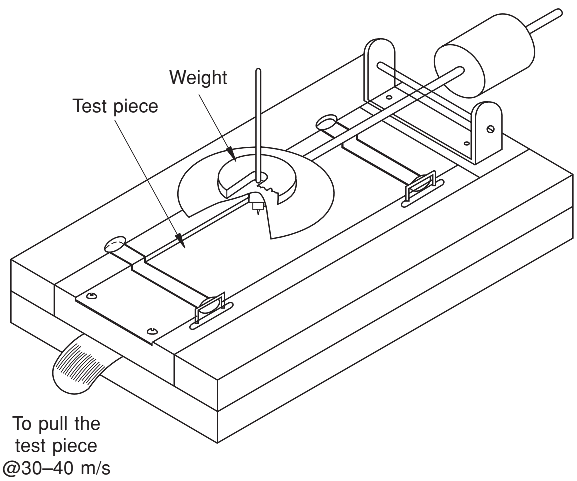


Figure A13.7 Scratch hardness testing apparatus

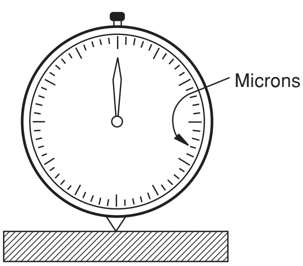


Figure A13.8 Thickness tester gauge

6 **Corrosion-resistance test** This can be done with the help of a salt spray test. The test piece is suspended in a salt spray chamber (Figure A13.9) for seven days in 100% relative humidity (IS 101 and IS 11864). After the test, the surface should have no signs of deterioration or corrosion.

7 **Acid resistance** This can be checked by using N/10 (H_2SO_4) solution. When a few drops are spilt on the test piece, or when the test piece is dipped for almost half an hour in the solution, it should develop no corrosion spots on the surface.

8 **Alkali resistance** This can be checked by N/10 (NaOH) solution. When a few drops are spilt on the test piece, or the test piece is dipped for almost half an hour in the solution, it should develop no corrosion spots on the surface.

A13.9 Peelable coating

The finished outer surfaces of the assemblies may be coated with a peelable coating compound which can be easily sprayed and air dried. The coat forms a translucent peelable film, suitable for protecting the finished surfaces during assembly, transportation and installation from scratches, oil marks, grease and dirt etc. The film can be neatly stripped after the equipment is finally installed.

Approximate spraying data are:

• Viscosity of peelable compound by Ford Cup No. 4	–	150–180 seconds
• Air pressure	–	3–4 kg/cm^2 (40–50 lb/in^2)
• Film thickness	–	20–30 microns (one coat is enough)
• Drying time	–	Surface dry 20–30 minutes and hard dry in about four hours

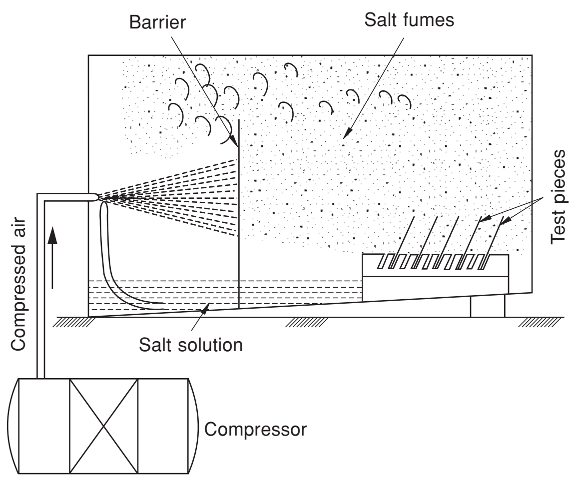


Figure A13.9 Salt spray chamber

A13.10 Effluent treatment and fume control

The process related to the paint shop does not impose a significant pollution load on the environment compared to many other industrial activities. It is, however, essential that all possible aspects of environmental pollution by wastewater, environmental hydrology, environmental hydraulics and pneumatics, air, solid waste, noise and hazardous wastes etc. are reviewed to control any kind of pollution within the prescribed limits. Otherwise subsequent tragedies, if caused by environmental negligence in the industrial processes, may lead to the formation of stricter environmental laws.

It is mandatory for a good paint shop to control polluting fumes and treat wastewater before it is discharged into the drains. Effluent treatment processes must be faithfully practised to prevent pollution of the environment and contamination of ponds, rivers or farmlands, wherever the wastewater is discharged.

A paint shop may pollute the surroundings in two possible ways: first, by acid and paint fumes that contaminate the inside of the plant and also pollute the outside environment; second, by the discharge of the pre-treatment tanks and over-sprayed paint that would pollute the drainage system or wherever it is finally discharged.

Note
The same process will hold good for treating effluents from an electroplating shop should it also exist with a paint shop. The effluents from an electroplating shop are strong wastes and need special consideration, as noted in the subsequent text and considered in Figure A13.12.

Physico-chemical analysis of effluent waste

In order to design a treatment system for industrial effluents, it is essential to determine the physico-chemical characteristics of the effluents. For this:

- Composite samples can be collected over an 8- or 24-hour period at half-hour or one-hour intervals from the regular effluent discharges such as from the pre-treatment tanks. The volume of each sample will depend upon the variation in the discharge flow rate.
- Grab samples can be collected from periodic discharges such as from the spray booth where the fresh water is replenished only periodically.
- Direct samples can be drawn from the pre-treatment tanks, when a new bath is made and the old one is drained out at an interval of two or three days or so, depending upon the quantum of work. The samples so collected should be analysed in a recognized test laboratory to ascertain the constituents of the effluents.

  A typical analysis report of the samples collected from a medium-sized paint shop handling about 5 MT/day of sheet-metal work, is provided in Table A13.5. These results are only of a final discharge, and may vary from plant to plant, depending upon the amount of work and the process of pre-treatment employed. Although the values obtained are not alarming, they do require effluent treatment, as the untreated effluent does not conform to the limits prescribed as standard tolerance level, to comply with the environmental legislation. Using environmental engineering practices one can obtain the desired standard levels in all parameters as in Table A13.6 or as may be prescribed by the local civic authorities.

Table A13.5 Average test results of effluent discharge (tank wash and spray booth mix of a medium-sized paint shop under consideration) before and after treatment

Sr. no.	*Pollutant*	*Test results*		*Tolerance level*
		Before treatment	*After treatment*	
1	BOD[1]	58 mg/l	25 mg/l	30 mg/l
2	COD[2]	604 mg/l	242 mg/l	250 mg/l
3	pH value	8.25	6.8	6.0–9.0
4	Total dissolved solids	4208 mg/l	1950 mg/l	–
5	Total suspended solids	546 mg/l	25 mg/l	100 mg/l
6	Oil and grease	9 mg/l	4 mg/l	10 mg/l
7	Phosphate as P	62.2 mg/l	Nil	5 mg/l
8	Chloride as Cl	1985 mg/l	510 mg/l	600 mg/l
9	Zinc as Zn	3.5 mg/l	Nil	5 mg/l

[1]Biochemical oxygen demand
[2]Chemical oxygen demand

Table A13.5 also indicates the test results of the samples of the final discharge when the effluents are treated along similar lines as discussed later. The test results are well within the tolerable limits. The recommended tolerance levels are provided in Table A13.6. Any constituent exceeding the prescribed limits must be properly treated before final discharge.

The recommended tolerance levels, as noted in Table A13.6, are applicable for a specific industry having surface finishing shop with disposal of treated effluent into inland surface waters. These levels may vary, depending upon the location of the plant. For sensitive or residential areas, for instance, the levels may be more conservative, decided by the local civic authorities. The effluent treatment will depend upon these values.

Effluent treatment and discharge of waste water

The appropriate method for effective effluent treatment is to segregate the stream of strong wastes from the rinse wastewater streams at the plant level before feeding into the effluent treatment plant and treat them separately, as shown in Figure A13.12. The strong wastes consist of discharges from electroplating plant, spray booth and spent passivation liquor etc. Accordingly all the pollutants noted in Table A13.5 can be treated in the following manner:

1 **Pre-treatment area** Acid fumes can be controlled by providing exhaust ducts (lip suction) on the acid pickling tank with a scrubber in the exhaust pipe as shown in Figure A13.1 to inhale the acid fumes from the tank and its surroundings. This then passes them through the scrubber, to have them dissolved in soda

Table A13.6 Recommended tolerance levels

Sr. no.	*Parameter*	*Recommended tolerance level (for the disposal of treated effluent into inland surface waters)*
1	Level of BOD (biochemical oxygen demand)	30 mg/ℓ
2	Level of COD (chemical oxygen demand)	250 mg/ℓ
3	Presence of alkali traces	Maximum up to 9.0, as measured by pH value
4	Presence of acid traces	Not less than 6.0 as measured by pH value *Notes:* (a) Clean water has a pH value of 7 to 7.5 (b) 1 mg/ℓ = parts per million (ppm) (c) pH: the logarithm of the reciprocal of the hydronium ion concentration. (Hydronium ion concentration of a solution varies on the degrees of alkalinity and acidity)
5	Total suspended solids	100 mg/ℓ
6	Oil and grease	10 mg/ℓ
7	Dissolved phosphates (as P)	5 mg/ℓ
8	Chlorides (as Cl)	600 mg/ℓ (drinking water contains around 400–500 mg/ℓ)
9	Sulphates (as SO_4)	1000 mg/ℓ
10	Cyanides (as CN)	0.2 mg/ℓ
11	Total chromium (as Cr)	2 mg/ℓ
12	Hexavalent chromium (Cr)	0.1 mg/ℓ
13	Zinc (as Zn)	5 mg/ℓ
14	Iron (as Fe)	3 mg/ℓ
15	Total heavy metals	10 mg/ℓ
16	Phenolic compounds (as C_6H_5OH)	1 mg/ℓ
17	Lead (as Pb)	0.1 mg/ℓ
18	Copper (as Cu)	2.0 mg/ℓ
19	Nickel (as Ni)	2.0 mg/ℓ
20	Bio-assay test	90% survival of fish after 96 hours
21	Temperature	Should not exceed 5% above the ambient temperature of the receiving body
22	Ammoniacal nitrogen (as N)	50 mg/ℓ
23	Total residual chlorine	1.0 mg/ℓ
24	Cadmium (as Cd)	2.0 mg/ℓ

Source Central Pollution Control Board (CPCB)—PCLS/4/2000–2001

water and then belch out the harmless fumes to the atmosphere. The acid fumes with soda water become converted into H_2SO_4 or HCl, depending upon the acid used for pickling. The saturated soda water collected at the bottom of the scrubber unit is transferred to the effluent treatment plant for further treatment. A typical flow diagram illustrating the fume treatment system is shown in Figure A13.10.

The wash water and the spent acid from all the pre-treatment tanks is also transferred to the effluent treatment plant for further treatment. Spent passivation liquor from the passivation tank is a strong waste and it may be collected through a separate pipeline to the effluent treatment plant, as shown in Figure A13.12.

2 Painting area (applicable to liquid paints)

- A spray booth can be installed as discussed above and provided with a running-water curtain system and an exhaust arrangement to absorb the over-sprayed paint and its fumes. The paint fumes are circulated through the curtain of water and the harmless fumes are then discharged to the atmosphere.
- The wash water mixed with paint which is a strong waste can be transferred (periodically, if the water curtain system is a closed cycle rather than a continuous running water system) to the effluent treatment plant for further treatment, as shown in Figure A13.12.

3 Ventilation The paint shop must be well ventilated and provided with exhaust fans to circulate fresh air within the shop. Roughly 20 to 30 air discharges per hour are considered good. Wet-painted surfaces, however, must be protected from suspended dust particles in the atmosphere and this can be done by promptly drying them in an oven. Air-drying paint therefore must be avoided as far as possible.

Wastewater treatment

Rapid industrialization has created many problems for the treatment and disposal of industrial wastes which are mainly responsible for the pollution of rivers, ponds and farmlands, when they are discharged directly, without proper treatment.

The effluents from a paint shop are slightly alkaline with moderate to weak BOD concentration. The effluents may also contain traces of heavy metals such as zinc and chromium which, if not treated, can create environmental and health hazards by harming crops, subsoil drinking water and aquatic flora and fauna. These effluents must be meticulously treated and neutralized before discharging them into the drains. The method of treatment is simple and can be performed along the following lines.

Figure A 13.11 illustrates a flow diagram of a simple effluent treatment plant. Chemicals are fed into the treatment tanks for neutralizing, coagulation, flocculation and detoxification. Sufficient air incorporation by means of surface or diffused aeration is carried out to replace the displaced oxygen in the waste waters. Figure A13.12 shows the layout and hydraulic profile of a typical effluent treatment plant which can be installed for the treatment of effluents generated from a medium-sized paint shop. In the figure we have assumed about 5 MT/day of sheet metal work being handled by the shop. The actual sizes and numbers of tanks will depend upon the amount of discharge and type of effluents. In Figure A13.12 the sizes given should be adequate for the size of paint shop we have considered. The process in the flow diagram

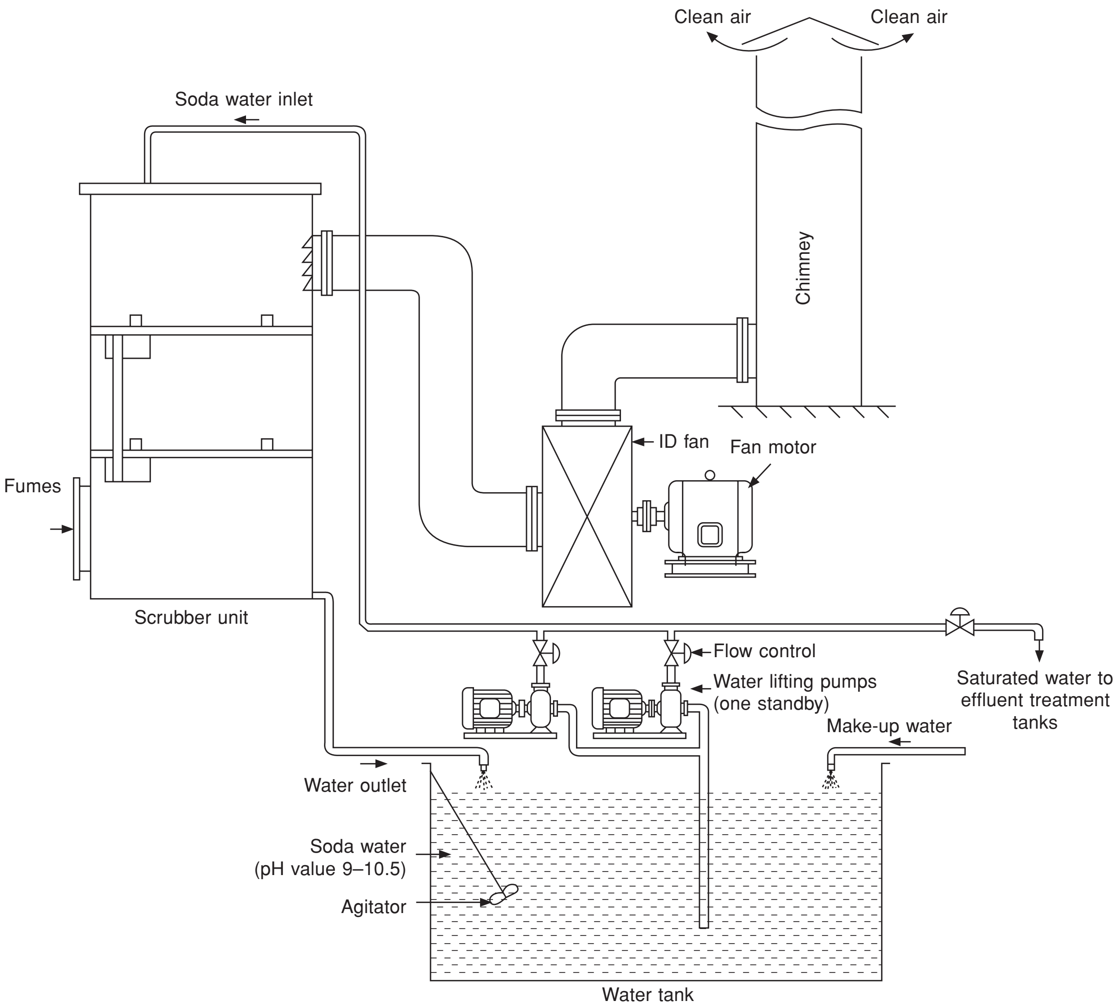


Figure A13.10 Typical flow diagram for fume treatment system

would be capable of handling all qualities of MS sheets. The brief treatment process is described below.

Brief description of wastewater treatment process

The effluents from various process operations are collected separately in two individual streams. The strong wastes at inlet 1 are fed into the oil and grease trap shown as tank No.1 in Figure A13.12. Two bar screens are fitted at the entry point of this tank in the incoming effluent channels provided for the prevention of removal of all adventitious matter present in the effluent. The rinse waters and other effluents contribute to inlet 2 and received at tank No. 3.

Effluent from the plant shall contain some amount of oil and fatty matter derived as waste and spillage from various unit operations. The oil and grease trap is a gravity separator of free fatty matter and foam from the effluent. Here, by allowing the effluent through over-flow and under-flow baffles with sufficient unstable detention period shall separate considerable amount of free oil. The free oil shall float on the surface of the effluent, scrapped away by manual means and collected separately. Mechanical oil scrappers can also be fitted in this chamber to increase the efficiency and to reduce manual errors.

The effluent discharge from the paint shop always possesses characteristic fluctuations. Hence, considerably large equalization cum collection chamber (tank No. 4) need be provided with air agitation system. In the equalization tank, effluent is homogenized to avoid shock loads. The air agitation by aeration grids provided in this tank facilitates equalization and aeration of the effluent.

Specific chemicals are added to strong effluents in tank No. 2 reaction chamber for the first stream to detoxify and separate the pollutants in insoluble form. Then, both the streams are taken into the equalization tank for further treatment as combined effluent.

From the effluent collection chamber (tank No. 4) the

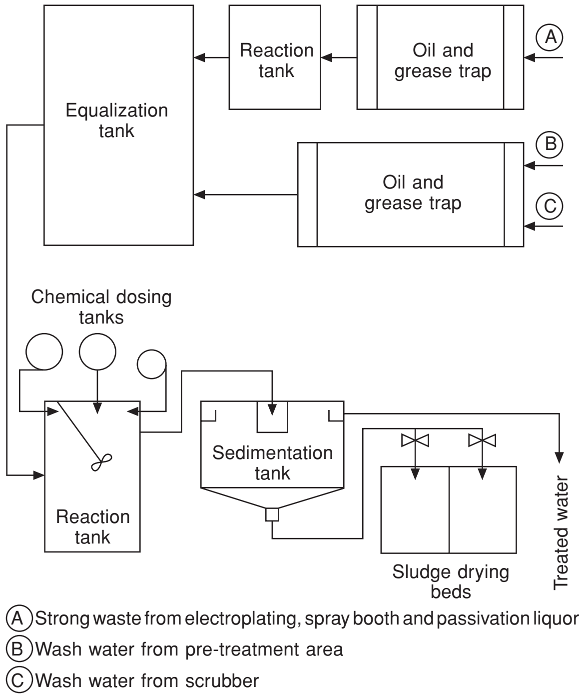


Figure A13.11 Flow diagram – effluent-treatment plant

effluent is transferred to the reaction tank (tank No. 5) through pumps. In the reaction tank, simple coagulants such as lime water and flocculants like alum and poly aluminium chloride are dosed for the reduction or oxidation of metallic salts dissolved in the effluent in order to scratch their toxicity and to separate the metals as inert precipitates. Moreover, the neutralization of the effluent also takes place by the addition of these chemicals. The latest practice is to go in for automatic dosing pumps to counter the manual errors in dosing and to optimize chemical consumption. The dosing pumps are connected with pH controllers with automatic temperature compensators, dip type electrodes and digital display boards fitted in the reaction tank. The pH controllers operate the dosing pumps and dose the required amount of chemicals in the effluent.

The mixed effluent from the reaction chamber (tank No. 5) flows into the clarification tank (tank No. 6). It is a rectangular hopper bottom tank with outside over-flow. Solids are withdrawn continuously by the under-flow at the rate at which they are supplied in the feed. All the settleable solids that settle down are removed as sludge from the bottom at regular intervals, on to the sludge drying beds (tank No. 8) for further de-watering and cake formation. The sludge dried shall be scrapped manually and collected into non-permeable hazardous storage tank. Disposal of this stored solid waste to the recognized hazardous disposal yards shall be carried out as per the statutory guidelines.

The clear effluent overflows from the clarifier system will conform to the Standards required for discharge into the drainage system as indicated earlier. The clarifier over-flow is collected in the polishing tank (tank No. 7) and from here the treated effluent is sent to the drain or distribution system for reuse for irrigation, in gardens, landscapes, agricultural lands and as rinsing water in the pre-treatment process.

Attention shall be paid towards the corrosion caused by handling of acidic and alkaline chemicals, to the civil structure and mechanical equipment installed off effluent treatment plants. All these shall be provided either with non-corrosive coating or made of non-corrosive materials where necessary.

For level of bio-chemical oxygen demand (BOD)

BOD is a measure of organic matter present in wastewater and can be degraded with the help of biomass. The level of BOD, if it exceeds the permissible limits of 30 mg/ℓ, will render the wastewater septic and unsafe for use. A higher level of BOD, when detected, can be degraded (neutralized) biologically with the help of biomass (micro-organism). The biomass consumes and degrades the organic matter present in the effluent. The organic chemicals present in the liquid paints mainly contribute the BOD in the paint shop effluent.

Since the discharges of effluents from such a paint shop is generally of a moderate nature the required BOD level is automatically maintained without any further treatment. Where required, a moderate quantity of additional oxygen supply, for the growth of biomass, can be made available through aeration of the wastewater. This can be carried out by passing oil-free compressed air through the effluent. The percolation of effluent dissolves additional oxygen from the atmosphere and helps the growth of bacteria. The oxygen requirement would be about 2 kg/kg of BOD removed.

In cases of still higher levels of BOD an additional supply of biomass may become essential, and this can be easily obtained from cow dung or municipal waste. To supplement biomass growth, nutrients such as urea and di-ammonium phosphate may be added.

Note
The effluent treatment plant shown in Figure A13.12 does not consist of any biomass based treatment system because the untreated effluent intake contains only small amount of BOD load as shown in Table A13.5.

For level of chemical oxygen demand (COD)

COD provides a measure of the oxygen equivalent to that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant. A higher level of COD can be degraded (neutralized) chemically. The level of COD, however, automatically reduces with the level of BOD and no further treatment is normally necessary.

To neutralize the alkali and acid effluents

The alkalinity or acidity in wastewater is usually determined by titration of the wastewater with a standard alkali or acid to the transition point of methyl orange

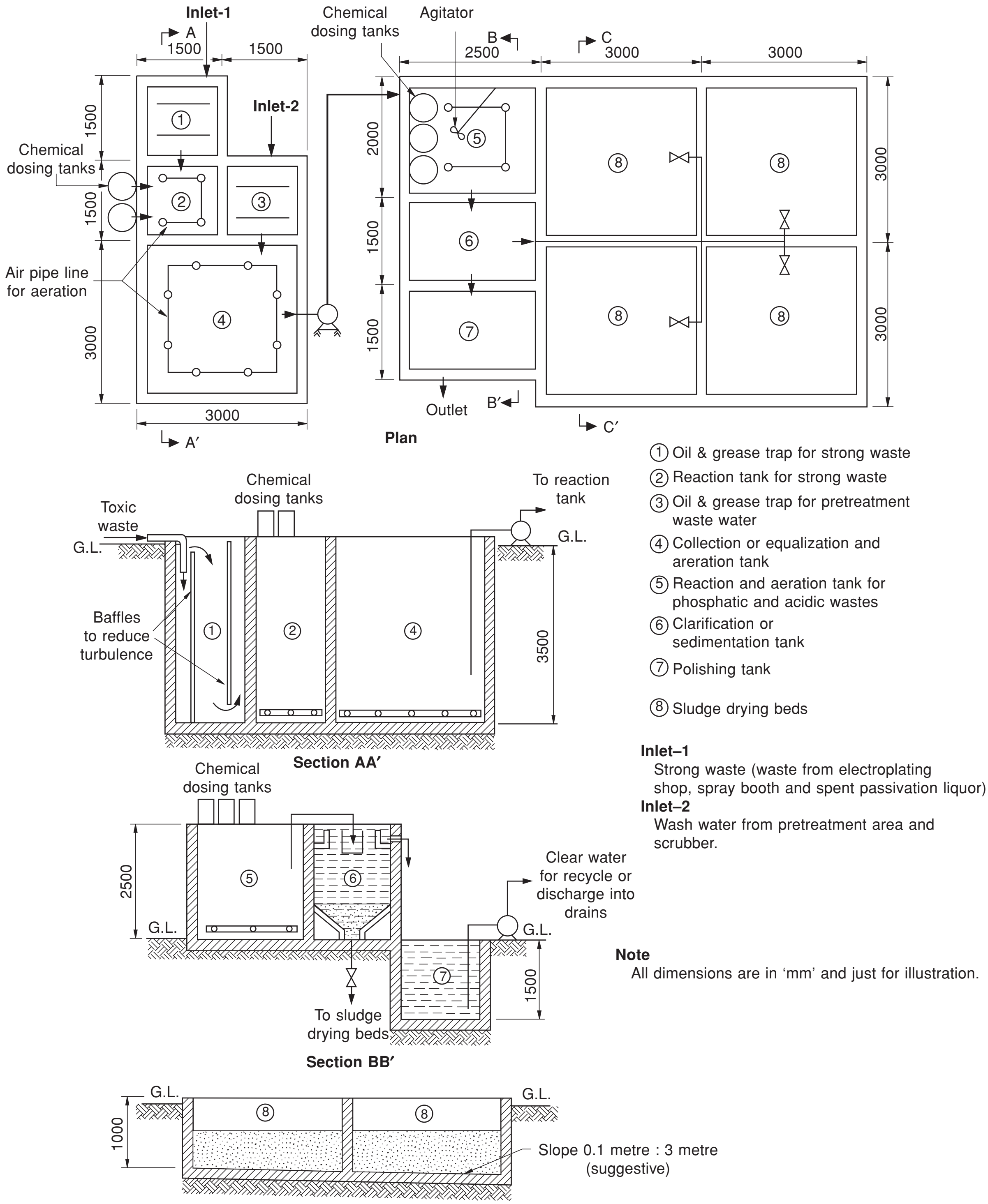


Figure A13.12 Layout of a typical effluent-treatment plant (pH range 3.1 to 4.4). Almost every effluent which is free from caustic alkalinity (pH less than 8.3) requires addition of acid to bring it to the methyl orange transition point. If the wastewater has a pH greater than 8.3, a titration with acid using a phenolphthalein indicator should be made and the result recorded as alkalinity to the phenolphthalein.

If the liquid is acid to methyl orange and alkalinity is absent the acidity must be determined. When methyl orange is used as an indicator for titration, the result may be recorded as mineral acid acidity and for a few organic acids, which give acidic solutions, the result may be recorded as acid to methyl orange. In some cases it may be desirable to determine total acidity by titration with alkali using phenolphthalein as an indicator, in which case the result is recorded as total acidity. It includes acidity due to carbon dioxide, as well as that due to mineral and organic acids.

The alkalinity and acidity is generally controlled, based on its nature and also by maintaining the pH value of the effluent discharge between 5.5. and 9.0, the ideal being around 7.5, as far as possible. The pH value can be checked with the help of a pH meter.

Acidic effluents can be treated with sodium carbonate (Na_2CO_3) or calcium hydroxide ($Ca(OH)_2$), i.e. lime water. The basic (alkaline) effluents can be treated with any mineral acid, preferably sulphuric acid (H_2SO_4), until the required pH value is obtained.

For phosphating and passivating effluents

These are also acidic in nature, and are taken care of automatically when the pH value of the effluents is maintained at the required level. If the passivation is carried out by using chromic acid, chromium must be treated separately by using sodium meta-bi-sulphite.

To remove solids

By using sedimentation (settling) tanks, the suspended solids can be removed as they settle at the bottom. Proper coagulants and flocculants such as lime and alum are utilized to convert the possible amount of dissolved matter into suspended solids.

The numbers and sizes of tanks will depend upon the amount of discharge and the type of effluents. For a normal paint shop, the size should be such that it is able to allow enough retention time for the suspended solids to settle at the bottom. To avoid turbulence in the tanks, the arrangement of inlet and discharge pipes can be made somewhat as illustrated in Figure A13.12. From the sedimentation tanks No. 8 clear water, which will meet the desired standards, can be discharged into the drains.

The scum of oil and grease, if any, collected at the surface of the tanks may be scooped out and destroyed with the waste paints. The sludge (solids) that settle at the bottom can be collected from the under-flow of the tanks or pumped out and disposed.

For zinc and other heavy metals

The treatment for zinc can be carried out with normal coagulants until it has formed any complex (chemical compound). Other heavy metals and cyanide constituents, however, will require special attention.

Disposal of waste primer, paint, oil and grease scum

These are considered to be highly hazardous wastes. The over-sprayed paint that collects at the bottom of the spray booth, and on its baffles, as well as the scum of oil and grease may be collected and stored in drums and sealed. It can then be disposed of at a recognized dumping ground meant for industrial wastes or destroyed in an incineration plant.

Relevant Standards

IEC	*Title*	*IS*	*BS*	*ISO*
–	Method of test for ready mixed paints and enamels.	101-1 to 9	BS 3900	3270/1984
–	Apparatus for salt spray test.	11864/1999	–	–
–	Method for specifying phosphate conversion coatings for metals.	3618/1991, 6005/1991	BS 3189/1996	9717/1990
–	Recommended practice for electroplating	3655/1985	–	–
–	Specification for electrostatic hand held spraying equipment for non flammable material for painting and finishing	–	BS EN 50059/1991	–

Relevant US Standards ANSI/NEMA and IEEE

ASTM B117/2003	Standard test method of salt spray (FOG) testing.
ASTM D1654-92/2000	Standard method for evaluation of painted or coated specimens subjected to corrosive environments.

Notes

1 In the table of relevant Standards while the latest editions of the Standards are provided, it is possible that revised editions have become available or some of them are even withdrawn. With the advances in technology and/or its application, the upgrading of Standards is a continuous process by different Standards organizations. It is therefore advisable that for more authentic references, one may consult the relevant organizations for the latest version of a Standard.

2 Some of the BS or IS Standards mentioned against IEC may not be identical.

3 The year noted against each Standard may also refer to the year it was last reaffirmed and not necessarily the year of publication.