DESIGN OF LOW VOLTAGE MAIN SWITCHBOARD (415/240V) FOR ELECTRICAL POWER DISTRIBUTION SYSTEM IN COMMERCIAL BUILDING

Oleh

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Abstrak

Projek ini mengemukakan rekabentuk sebuah Papan Suis Utama Voltan Rendah (415/240V) dalam sebuah bangunan komersial dengan tujuan untuk mengagihkan kuasa elektrik yang diperlukan oleh beban beserta sistem perlindungan. Objektif utama projek ini ialah merekabentuk Papan Suis Utama Voltan Rendah termasuk Sistem Tunggu Sedia (Penjana Diesel dan Bekalan Kuasa Tanpa Gangguan), Sistem Perlindungan Kebakaran dan Sistem Televisyen Antenna Satelit Utama.. Selain, projek ini memberi lebih pemahaman tentang peralatan elektrik seperti pemutus litar, sistem bus yang digunakan dalam Papan Suis Utama, peranti perlindungan arus berlebihan dan arus bocor ke bumi dan lain-lain peralatan elektrik. Rekabentuk projek bermula dengan pengiraan jumlah keseluruhan data beban dimana permintaan maksima P = 850 kW, arus keseluruhan, I = 850 A dan voltan perkhidmatan, V = 415 V (Voltan Rendah). Dengan maklumat yang diperolehi daripada pengiraan data beban, hasilnya ialah kita boleh menentukan saiz kabel utama, pemutus litar utama, peralatan mengira dan meter beserta lain – lain peralatan elektrik yang terdapat didalam Papan Suis Utama. Untuk merekabentuk sistem yang lebih baik, kajian mengenai projek ini harus dijalankan dengan lebih mendalam di masa hadapan.

Abstract

This project emphasizes the design of Low Voltage Main Switchboard (415/240V) in commercial building with the purpose to distribute electrical power to the load together with protection system. The main objective of this project is to design a Low Voltage Main Switchboard consists of Emergency Standby Supply (Generator set and Uninterruptible Power Supply), Fire Protection System and Satellite Master Antenna Television (SMATV). Besides that, this project give a clear understanding about electrical equipment such as circuit breaker, busbar system used in Main Switchboard, protection relays such as overcurrent and earth leakage protection and many others equipment. The project design starts with load data calculation where maximum demand P = 520 kW, total current I = 850 A and voltage supply V = 415 V (Low Voltage). With thi information we get from the load data calculation, the result is we can size up the main cable, main circuit breaker, metering and measuring instrument, and others equipment include in Main Switchboard. For future work, more research could be done in this project in order to design a high efficient system in electrical power distribution.

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List of Contents

CHAPTER 1: INTRODUCTION

1.1 Background

Electrical power distribution system plays an important rule in order to distribute all the electric need by an industrial, commercial or residential consumer. It may be high, medium or low voltages depend on the total power demand required by the consumer. So, in manner to fulfill this requirement, we need an effective system where the function is to distribute an electric power efficiently, completely with a safety configuration needed in the system.

This project aims is to design a Low Voltage Main Switchboard for electrical distribution and protection system for commercial building name by Marine Hub Logistic. Main switchboard is a device that directs electricity from one source to another. It is contains switches that allow electricity to be redirected. The operator is protected from electrocution by safety switches in manner to provide maximum safety to the electrical equipment from damage during an error in electrical power distribution system.

In this project, the design of Low Voltage Main Switchboard for Marine Hub Logistic building covers the electrical loads such as lighting, power point, Air Conditioning system, Lift system, machine accessories used in workshop, Fire Protection system and Satellite Master Antenna Television System (SMATV). Besides that, emergency standby power supply also be provided in this system design. Protection of internal installation against lightning for building protection also covers in this project.

Marine Hub Logistic building consists of seventh floor office unit plus with one unit workshop. The building will be developing by this September, 2007 costly about RM 7 million. This project will be done by Penang Development Corporation Consultancy Sdn. Bhd. The project client is KBH Sdn. Bhd, where the company running business on shipping field and they are from Singapore.

1.2 Objectives

The main objectives design of Low Voltage Main Switchboard to understand clearly how the concepts of electrical power distribution system in commercial building. Instead of that, focus this project will start from the incoming supply in Main Switchboard to the overall electrical load installation in the building. Together with this, Fire Protection, Satellite Master Antenna Television system design and emergency standby supply also include in this project. The following description highlighted below is the main project focuses in order to fulfill the project objectives.

The internal low electrical installation is focusing in circuit breaker, busbar, protection relay, measuring and metering, distribution boards, residual current devices, earthing system, lightning and surge protection system, cables, capacitor bank and wiring system.

For safety of the human and property, protection against fire covers by Fire Protection System. The Fire Protection system design consists of hose reel, heat detector, breakglass and alarm bell.

Satellite Master Antenna Television system focus on the selection of frequency need for Television and Radio system in order to receive clear picture quality and radio receiving.

Finally, emergency standby supply such as diesel generator set and Uninterruptible power supply using to ensure continuously power supply during electrical power failure in the electric power system.

1.3 Project Overview

The following gives an overview of the project, which is divided into the main supply system, fire system, emergency supply system and telecommunication system design.

1.3.1 Main Supply System

The main supply system mean here is Main Switchboard, where the system consists of the following devices listed below where suitable method of installation, selection of size, types and current rating and setting must be consider.

- Earthing System
- Lightning and Surge Protection
- Busbar System
- Circuit Breakers
- Protection Relays
- Metering Instrument
- Current Transformer
- Residual Current Operated Circuit Breaker
- Main, submain and circuit cables
- Capacitor Bank
- Sub-Switch and Final Distribution Board

1.3.2 Emergency Standby Supply

In the event of power outage in the main supply system, the emergency supply must be able to provide power supply to certain load and sensitive load. The emergency supply can be divided into 2 types.

- Diesel generator set, provide continuously supply to essentials load such as common lighting and power, fire alarm pump and panel and sensitive load.

- Uninterruptible Power Supply,provide power supply to computer load without any interruption in the system.

1.3.3 Fire Protection System

This system function to provide protection against fire inside the building. The system consists of heat detector to detect a fire based on temperature changes, breakglass use to manually activate alarm system, alarm bell to give warning in the event fire, control panel to control the devices mention above and hose reel system use to clear the fire.

1.3.4 Telecommunication Services

Satellite Master Antenna Television System use in this system to make sure the building received and clear radio frequency and good picture quality based on the frequency range selection.

1.4 Report Guide

This report project gives the design of Low Voltage Main Switchboard for commercial building. The report is divided into 6 chapters.

Chapter 1 gives the information related to project background. Discuss the objectives of the project and what project focuses in order to fulfill the project requirement. Besides that, this part gives a short overview of the system design.

Chapter 2 consists of literature review related to the project. The literature gives an idea on how the system design goes on the design of Low Voltage Main Switchboard, Fire Protection System, Standby Power Supply and Satellite Master Antenna TV.

Chapter 3 gives an overall procedure carries out for system design such as design of Main Switchboard, Capacitor bank, Earthing system, Lightning and Surge Protection system, Standby Power Supply system and Satellite Master Antenna TV.

Chapter 4 gives an overall system design for this project based on the following procedures gives in chapter 3.

Chapter 5 provides sufficient information on wiring system of electrical power distribution system. Analysis and discussion on the system design.

Chapter 6 finally, the last part of this report comes out with the conclusion on the system and some suggestion in order to improve the design on this project

CHAPTER 2: LITERATURE REVIEW

2.1 Main Switchboard (Electric Switchboard)

An electric switchboard is a device that directs electricity from one source to another. It is an assembly of panels, each of which contains switches that allow electricity to be redirected. The operator is protected from electrocution by safety switches and fuses. There can also be controls for the supply of electricity to the switchboard, coming from a generator or bank of electrical generators, especially frequency control of AC power and load sharing controls, plus gauges showing frequency and perhaps a synchroscope. The amount of power going into a switchboard must always equal the power going out to the loads.

Inside the switchboard is a bank of busbars generally wide strips of copper to which the switchgear is connected. These act to allow the flow of large currents through the switchboard, and are generally bare and not insulated. Power to a switchboard should first be isolated before a switchboard is opened for maintenance, as the bare Busbars represent a severe electrocution hazard. Working on a live switchboard is rarely necessary, and if it is done then precautions should be taken, such as standing on a thick rubber mat, the use of gloves etc.

2.2 Busbar

The word busbar, derived from the Latin word omnibus ('for all'), gives the idea of a universal system of conveyance. In the electrical sense, the term bus is used to describe a junction of circuits, usually in the form of a small number of inputs and many outputs. 'Busbar' describes the form the bus system usually takes, a bar or bars of conducting material.

In any electrical circuit some electrical energy is lost as heat which, if not kept within safe limits, may impair the performance of the system. This energy loss, which also represents a financial loss over a period of time, is proportional to the effective resistance of the conductor and the square of the current flowing through it. A low resistance therefore means a low loss; a factor of increasing importance as the magnitude of the current increases.

The capacities of modern-day electrical plant and machinery are such that the power handled by their control systems gives rise to very large forces. Busbars, like all the other equipment in the system, have to be able to withstand these forces without damage. It is essential that the materials used in their construction should have the best possible mechanical properties and are designed to operate within the temperature limits laid down in BS 159, BS EN 60439-1:1994, or other national or international standards.

A conductor material should therefore have the following properties if it is to be produced efficiently and have low running costs from the point of view of energy consumption and maintenance:

a) Low electrical and thermal resistance
b) High mechanical strength in tension, compression and shear
c) High resistance to fatigue failure
d) Low electrical resistance of surface films
e) Ease of fabrication
f) High resistance to corrosion
g) Competitive first cost and high eventual recovery value

This combination of properties is met best by copper. Aluminium is the main alternative material, but a comparison of the properties of the two metals shows that in nearly all respects copper is the superior material.

Busbars can be sub-divided into the following categories, with individual busbar systems in many cases being constructed from several different types:

(a) Air insulated with open phase conductors

(b) Air insulated with segregating barriers between conductors of different phases.

(c) Totally enclosed but having the construction as those for (a) and (b)

(d) Air insulated where each phase is fully isolated from its adjacent phase(s) by an earthed enclosure. These are usually called 'Isolated Phase Busbars'.

(e) Force-cooled busbar systems constructed as (a) to (d) but using air, water, etc. as the cooling medium under forced conditions (fan, pump, etc.).

(f) Gas insulated busbars. These are usually constructed as type (e) but use a gas other than air such as SF6, (sulphur hexafluoride).

(g) Totally enclosed busbars using compound or oil as the insulation medium.

The type of busbar system selected for a specific duty is determined by requirements of voltage, current, frequency, electrical safety, reliability, short-circuit currents and environmental considerations. Table 2.1 outlines how these factors apply to the design of busbars in electricity generation and industrial processes.

Table 2.1 Comparison of typical design requirements for power generation and industrial process system.

	Feature	Generation	Industrial Processes
1	Voltage drop	Normally not important	Important
2	Temperature rise	Usually near to maximum allowable. Capitalisation becoming important.	In many cases low due to optimisation of first cost and running costs
3	Current range	Zero to 40 k A a .c . with frequencies of zero to 400 Hz.	Zero to 200 kA a.c. and d.c.
4	Jointing and connections	Usually bolted but high current applications are often fully welded. Joint preparation very important	Usually bolted. Joint preparation very important.
5	Cross-sectional area	Usually minimum. Somewhat larger if optimisation is required.	Usually larger than minimum required due to optimisation and voltage drop considerations.
6	Kelvin's Law	Not applied. Other forms of optimisation are often used.	Applies. Also other forms of optimisation and capitalisation used
	Construction	Up to 36 k V. Individually	Usually low voltage.

7		engineered using basic designs and concepts.	Individually engineered. Standard products for low current/voltage applications.
8	Enclosures	Totally enclosed with or without ventilation.	Usually open. Enclosed or protected by screens when using standard products.
9	Fault capacity	Usually large. Designed to meet system requirement.	Usually similar to running current. Standard products to suit system short circuit.
10	Phase arrangement	Normally 3 phase flat though sometimes trefoil.	Normally flat but transposition used to improve current distribution on large systems
11	Load factor	Usually high. Normally 1.0.	Usually high but many have widely varying loads.
12	Cost	Low when compared with associated plant.	Major consideration in many cases. Particularly when optimisation/capitalisation is used.
13	Effects of failure	Very serious. High energies dissipated into fault.	Limited by low voltage and busbar size.
14	Copper type	High conductivity.	High conductivity.

At the present time the only two commercially available materials suitable for conductor purposes are copper and aluminium. The table below gives a comparison of some of their properties. It can be seen that for conductivity and strength, high conductivity copper is superior to aluminium. The only disadvantage of copper is its density; for a given current and temperature rise, an aluminium conductor would be lighter, even though its cross-section would be larger. In enclosed systems however, space considerations are of greater importance than weight. Even in open-air systems the weight of the busbars, which are supported at intervals, is not necessarily the decisive factor.

Table 2.2 Typical relative properties of copper and aluminium

	Copper (CW004A)	Aluminium (1350)	Units
Electrical conductivity (annealed)	101	61	% IACS
Electrical resistivity (annealed)	1.72	2.83	Ώ.cm
Temperature coefficient of resistance(annealed)	0.0039	0.004	/° C
Thermal conductivity at 20°C	397	230	W/mK
Coefficient of expansion	17 x 10-6	23 x 10-6	/° C
Tensile strength (annealed)	200 - 250	50 - 60	N/mm^2
Tensile strength (half–hard)	260 - 300	85 - 100	N/mm^2
0.2% proof stress (annealed)	50 -55	20 - 30	N/mm^2
0.2% proof stress (half–hard)	170 - 200	60 - 65	N/mm^2
Elastic modulus	116 – 130	70	kN/mm^2
Specific heat	385	900	J/kg K
Density	8.91	2.70	g/cm^3
Melting point	1083	660	°C

The electromagnetic stresses set up in the bar are usually more severe than the stress introduced by its weight. In particular, heavy current-carrying equipment necessitates the use of large size conductors, and space considerations may be important. It should be realised that the use of copper at higher operating temperatures than would be permissible for aluminium allows smaller and lighter copper sections to be used than would be required at lower temperatures.

The ability of copper to absorb the heavy electromagnetic and thermal stresses generated by overload conditions also gives a considerable factor of safety. Other factors, such as the cost of frequent supports for the relatively limp aluminium, and the greater cost of insulation of the larger surface area, must be considered when evaluating the materials.

From published creep data, it can be seen that high conductivity aluminium exhibits evidence of significant creep at ambient temperature if heavily stressed. At the same stress, a similar rate of creep is only shown by high conductivity copper at a temperature of 150°C, which is above the usual operating temperature of busbars.

Table 2.3 Comparison of creep and fatigue properties of high conductivity copper and aluminium

(a) Creep properties

Material	Testing Temp. (°C)	Min. Creep Rate (% per 1000 h)	Stress (N/mm²)
Al (1080) annealed	20	0.022	26*
HC Cu annealed	150	0.022	26*
Cu-0.086% Ag 50% c.w.	130	0.004	138
Cu-0.086% Ag 50% c.w.	225	0.029	96

(b) Fatigue properties

Material		Fatigue strength (N/mm²)	No. of cycles x 106
HC Al	annealed	20	50
	half-hard (H8)	45	50
HC Copper	annealed	62	300
	half-hard	115	300

If much higher stresses or temperatures are to be allowed for, copper containing small amounts (about 0.1%) of silver can be used successfully. The creep resistance and softening resistance of copper-silver alloys increase with increasing silver content. In the conditions in which high conductivity aluminium and copper are used, either annealed (or as-welded) or half-hard, the fatigue strength of copper is approximately double that of aluminium. This gives a useful reserve of strength against failure initiated by mechanical or thermal cycling.

The greater hardness of copper compared with aluminium gives it better resistance to mechanical damage both during erection and in service. It is also less likely to develop problems in clamped joints due to cold metal flow under the prolonged application of a high contact pressure. Its higher modulus of elasticity gives it greater beam stiffness compared with an aluminium conductor of the same dimensions. The temperature variations encountered under service conditions require a certain amount of flexibility to be allowed for in the design. The lower coefficient of linear expansion of copper reduces the degree of flexibility required.

Because copper is less prone to the formation of high resistance surface oxide films than aluminium, good quality mechanical joints are easier to produce in copper conductors. Welded joints are also readily made. Switch contacts and similar parts are nearly always produced from copper or a copper alloy. The use of copper for the busbars to which these parts are connected therefore avoids contacts between dissimilar metals and the inherent jointing and corrosion problems associated with them.

The higher melting point and thermal conductivity of copper reduce the possibility of damage resulting from hot spots or accidental flashovers in service. If arcing occurs, copper busbars are less likely to support the arc than aluminium. Table 2. 4 shows that copper can self-extinguish arcs across smaller separations, and at higher busbar currents. This self-extinguishing behavior is related to the much larger heat input required to vaporise copper than aluminium.

Table 2.4 Self-extinguishing arcs in copper and aluminium busbars

	Copper	Aluminium
Minimum busbar spacing, mm	50	100
Maximum current per busbar, A	4500	3220

Copper liberates considerably less heat during oxidation than aluminium and is therefore much less likely to sustain combustion in the case of accidental ignition by an arc. The large amounts of heat liberated by the oxidation of aluminium in this event are sufficient to vaporise more metal than was originally oxidised. This vaporised aluminium can itself rapidly oxidise, thus sustaining the reaction. The excess heat generated in this way heats nearby materials, including the busbar itself, the air and any supporting fixtures. As the busbar and air temperatures rise, the rates of the vaporisation and oxidation increase, so accelerating the whole process. As the air temperature is increased, the air expands and propels hot oxide particles. The busbar may reach its melting point, further increasing the rate of oxidation and providing hot liquid to be propelled, while other materials such as wood panels may be raised to their ignition temperatures. These dangers are obviated by the use of copper busbars.

Finally, copper is an economical conductor material. It gives long and reliable service at minimum maintenance costs, and when an installation is eventually replaced the copper will have a high recovery value. Because of its many advantages, copper is still used worldwide as an electrical conductor material despite attempts at substitution.

2.3 Overcurrent and Earth Fault Protection

Overcurrent relays and fuses are the most commonly applied form of distribution power system protection. Relays are activated from current transformer secondary with typical secondary ratings of 1A or 5A. These relays were originally electromechanical devices but modern versions are microprocessor based and incorporate many features and refinements to increase versatility and improve coordination between relays and fuses on the same feeder.

The generic term relay is used for a collection of elements that are associated with phase or ground fault protection supplied from current transformers to provide instantaneous or inverse-time phase and ground fault protection, with or without time delay characteristics. These elements are programmable to produce characteristics that can replicate fuse curves or multi-function curves composed of definite-time, inverse time and instantaneous components. Inverse-time elements are available with inverse, moderately inverse, very inverse, and extremely inverse characteristics specified by IEEE or IEC standards. Settings suitable for phase or ground fault protection are available, sometimes along with breaker fail backup protection.

A common feature for both phase and ground fault elements is selection between definite-time and inverse-time characteristics for different current operating levels commonly defined as high set and low set. High set elements provide fast operation to clear high fault current levels thus minimizing plant damage. In most cases, coordination with downstream protection is not an issue. Low set elements are required to properly coordinate with upstream and downstream protection and ensure adequate time margins between operating characteristics over the range of feeder fault current levels. A range of independently set timing elements provides a great deal of flexibility in dealing with the requirements to provide these margins.

Relay element settings are described generically in time and multiples of primary current or relay rated current. These in turn, can be translated into time multipliers and relay tap settings by reference to the manufacturer’s literature. In practice, most utilities employ a limited number of device types.

For application purposes, overcurrent relay elements are separated into:

(i) Instantaneous

(ii) Definite time
(iii) Inverse time

Instantaneous elements are simple devices that operate at a given level of current. In practice, the higher the fault current above the current setting the faster the operation. There is a minimum time of operation dictated by the rate at which the fault current rises. The operating current related to the element setting is not particularly accurate since the elements are intended for backup protection purposes or to achieve fast fault clearance where accuracy is not an issue.

A particular form of instantaneous element is designed to increase the setting accuracy by filtering out the dc component of fault current and is used where improved accuracy is an issue in ensuring correct discrimination between protective devices. Definite time-overcurrent elements are simply instantaneous overcurrent elements assigned a given current setting and controlled by a timer set to operate at a designated time.

Inverse-time elements are designed to operate according to the inverse-time curve. They have a definite minimum operating current, determined by the current setting, and a definite minimum time of operation, determined by the time setting. The curve is asymptotic to both the time and current axes. The shape of the curve is chosen according to whether an inverse-time, a very inverse-time, or an extremely inverse-time characteristic is desired.

Inverse-time elements have a range of current settings that determine the currents, defined in amps, supplied by the current transformer at which the element is designed to just operate. For example, a 1 amp rated phase fault element usually has tap settings of 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0 amps, being the nominal currents at which the relay operates. In practice, a 1.0 amp setting requires typically 1.1 amps or more to operate the element in a finite time. The companion ground fault element is likely to have a setting range of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 amps.

Phase fault (overcurrent relay) and ground fault (earth fault relay) detection requires separate elements designed to cover the range of prospective phase and ground fault currents. Typically, ground fault elements have lower current settings than phase faults because of the relative values of the fault magnitudes and the fact that ground fault element current settings need not account for peak loading currents on a feeder. They can be set at relatively low values of fault current for greater sensitivity. All the elements for phase and ground fault are incorporated in one relay for compactness. In addition to the overcurrent elements themselves, the relay will include targets or flags for each element that signifies physically or electronically that the element has operated in the event of a fault.

A common combination for overcurrent relays is an element supplied from A phase and another supplied from C phase. The ground fault element is supplied from the residual current from the three phases. At least one phase element will operate for any phase-phase fault. A ground fault energizes one phase and the ground fault element for faults on A or C phases and the ground fault element only for a B phase ground fault. Where greater security is desired, all three-phase fault elements are included in addition to the residually connected ground fault element. Now two fault elements operate for any phase-phase or phase-ground fault.

2.4 Current Tranformer

Current transformers (CTs) are an indispensable tool to aid in the measurement of AC current. They provide a means of scaling a large primary (input) current into a smaller, manageable output (secondary) current for measurement and instrumentation.

A CT utilizes the strength of the magnetic field around the conductor to form an induced current on its secondary windings. This indirect method of interfacing allows for easy installation and provides a high level of isolation between the primary circuit and secondary measurement circuits.

A CT is useful for measurements made on AC waveforms. It acts just like a regular voltage transformer, but typically has only one primary winding (the wire carrying the current to be measured). Unlike a regular voltage transformer, there is no physical connection made to the measured line. The CT uses magnetic fields generated by the AC current flowing through the primary wire to induce a secondary current. The ratio of the number of secondary turns to them number of primary turns determines the amplitude of the current on the output. The output of a CT acts as a current source.

Traditionally, CTs were designed to have a full scale output of 5A for a given full scale primary current. Typical full scale input currents ranged from 50 to 2000 amps. This would be represented as 50:5 or 2000:5. In a 2000:5 CT, 5A flows in the secondary winding when 2000A is flowing through the primary winding. By changing the number of secondary windings, the CT manufacturer defines the input full scale.

5A is a considerable amount of current, and it was designed to be used with electromagnetic meters, to provide the power to move the magnetic needles or power protective relays. This style of CT has advantages in that the metering equipment is all configured for a 5A input. The appropriate CT can therefore be chosen to determine the full scale measurement range of the metering equipment. As far as the meter is concerned, it will see a range between 0-5A, since the CT is chosen for the proper maximum primary current. Many measurement and monitoring devices support 5A CT inputs, as this has become a defacto standard in the metering industry, especially for large building or sub-metering installations.

However, due to the relatively large (5A) current requirement, these CTs require a larger, heavier core, and a larger wire gauge. This translates to a larger, heavier final product and higher costs.

Moreover, these CTs can be extremely dangerous because of the large voltages that are induced when the CT secondaries are not shorted. Since a CT acts as a current source, following Ohm’s law, V=IR. If the resistance is increased (a very high value when open circuited), the induced voltage becomes very high. Many of these CTs have enough power to cause large arcing across open secondary wires.

Special shorting blocks are required to ensure that the CTs remain shorted, even if disconnected from the meter. The induced voltages are large enough to cause serious injury or even death if the appropriate precautions are not taken to prevent open circuiting the output. The added cost and burden of the shorting blocks and their installation must be considered when using these CTs.

2.5 Circuit Breaker

Figure 2.1 A 2 pole MCB

A circuit breaker is an automatically-operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are made in varying sizes, from small devices that protect an individual household appliance up to large switchgear designed to protect high voltage circuits feeding an entire city.

Magnetic circuit breakers are implemented using a solenoid (electromagnet) whose pulling force increases with the current. The circuit breaker's contacts are held closed by a latch and, as the current in the solenoid increases beyond the rating of the circuit breaker, the solenoid's pull releases the latch which then allows the contacts to open by spring action. Some types of magnetic breakers incorporate a hydraulic time delay feature wherein the solenoid core is located in a tube containing a viscous fluid. The core is restrained by a spring until the current exceeds the breaker rating. During an overload, the solenoid pulls the core through the fluid to close the magnetic circuit, which then provides sufficient force to release the latch. The delay permits brief current surges beyond normal running current for motor starting, energizing equipment, etc. Short circuit currents provide sufficient solenoid force to release the latch regardless of core position thus bypassing the delay feature. Ambient temperature affects the time delay but does not affect the current rating of a magnetic breaker.

Thermal breakers use a bimetallic strip, which heats and bends with increased current, and is similarly arranged to release the latch. This type is commonly used with motor control circuits. Thermal breakers often have a compensation element to reduce the effect of ambient temperature on the device rating.

Thermomagnetic circuit breakers, which are the type found in most distribution boards, incorporate both techniques with the electromagnet responding instantaneously to large surges in current (short circuits) and the bimetallic strip responding to less extreme but longer-term overcurrent conditions.

Circuit breakers for larger currents are usually arranged with pilot devices to sense a fault current and to operate the trip opening mechanism.

Under short-circuit conditions, a current many times greater than normal can flow. When electrical contacts open to interrupt a large current, there is a tendency for an arc to form between the opened contacts, which would allow the flow of current to continue. Therefore, circuit breakers must incorporate various features to divide and extinguish the arc. In air-insulated and miniature breakers an arc chutes structure consisting (often) of metal plates or ceramic ridges cools the arc, and blowout coils deflect the arc into the arc chute. Larger circuit breakers such as those used in electrical power distribution may use vacuum, an inert gas such as Sulfur Hexafluoride or have contacts immersed in oil to suppress the arc.

The maximum short-circuit current that a breaker can interrupt is determined by testing. Application of a breaker in a circuit with a prospective short-circuit current higher than the breaker's interrupting capacity rating may result in failure of the breaker to safely interrupt a fault. In a worst-case scenario the breaker may successfully interrupt the fault, only to explode when reset, injuring the technician.

Small circuit breakers are either installed directly in equipment, or are arranged in a breaker panel. Power circuit breakers are built into switchgear cabinets. High-voltage breakers may be free-standing outdoor equipment or a component of a gas-insulated switchgear line-up.

Figure 2.2 show photographs of the internal details of a 10 ampere European DIN rail mounted thermal-magnetic miniature circuit breaker. Circuit breakers such as this are the most common style in modern domestic consumer units and commercial electrical distribution boards throughout Europe. Unfortunately, while the size and shape of the opening in the front and its elevation from the rail are standardised, the arrangements for busbar connections are not, so installers need to take care that the chosen breaker fits the busbar in a particular board.

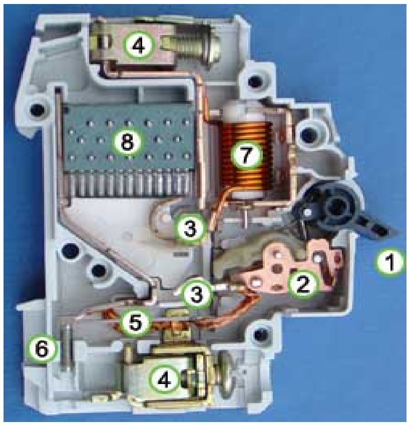

Figure 2.2 Low Voltage Circuit Breaker

1. Actuator lever
   Used to manually trip and reset the circuit breaker. Also indicates the status of the circuit breaker (On or Off/tripped). Most breakers are designed so they can still trip even if the lever is held or locked in the on position. This is sometimes referred to as "free trip" or "positive trip" operation.

2. Actuator mechanism
   Forces the contacts together or apart.

3. Contacts
   Allow current to flow when touching and break the flow of current moved apart.

4. Terminals

5. Bimetallic strip

6. Calibration screw
   Allows the manufacturer to precisely adjust the trip current of the device after assembly.

7. Solenoid

8. Arc divider / extinguisher

International Standard IEC 60898-1 and European Standard EN 60898-1 define the rated current In of a circuit breaker for household applications as the current that the breaker is designed to carry continuously (at an ambient air temperature of 30 °C). The commonly-available preferred values for the rated current are 6 A, 10 A, 13 A, 16 A, 20

A, 25 A, 32 A, 40 A, 50 A, 63 A, 80 A and 100 A (Renard series, slightly modified to include current limit of British BS 1363 sockets).

Figure 2.3 Three pole common trip breaker for supplying a three-phase device. This breaker has a 2 ampere rating

When supplying a branch circuit with more than one live conductor, each live conductor must be protected by a breaker pole. To ensure that all live conductors are interrupted when any pole trips, a "common trip" breaker must be used. These may either contain two or three tripping mechanisms within one case, or for small breakers, may externally tie the poles together via their operating handles. Two pole common trip breakers are common on 120/240 volt systems where 240 volt loads (including major appliances or further distribution boards) span the two out-of-phase live wires. Three pole common trip breakers are typically used to supply three phase power to large motors or further.

There are many different technologies used in circuit breakers and they do not always fall into distinct categories. Types that are common in domestic, commercial and light industrial applications at low voltage (less than 1000 V) include:

- MCB (Miniature Circuit Breaker), rated current not more than 100 A. Trip characteristics normally not adjustable. Thermal or thermal-magnetic operation. Breakers illustrated above are in this category.

- MCCB (Moulded Case Circuit Breaker), rated current up to 1000 A. Thermal or thermal-magnetic operation. Trip current may be adjustable.

Electric power systems require the breaking of higher currents at higher voltages. Examples of high-voltage AC circuit breakers are:

- Vacuum circuit breaker - With rated current up to 3000 A, these breakers interrupt the current by creating and extinguishing the arc in a vacuum container. These can only be practically applied for voltages up to about 35,000 V, which corresponds roughly to the medium-voltage range of power systems. Vacuum circuit breakers tend to have longer life expectancies between overhaul than do air circuit breakers.

- Air circuit breaker - Rated current up to 10,000 A. Trip characteristics often fully adjustable including configurable trip thresholds and delays. Usually electronically controlled, though some models are microprocessor controlled. Often used for main power distribution in large industrial plant, where the breakers are arranged in draw-out enclosures for ease of maintenance.

2.6 Residual Current Device

Figure 2.4 A residual current device (RCD

A residual current device (RCD), or residual current circuit breaker (RCCB), is an electrical wiring device that disconnects a circuit whenever it detects that the flow of current is not balanced between the phase ("hot") conductor and the neutral conductor. The presumption is that such an imbalance may represent current leakage through the body of a person who is grounded and accidentally touching the energized part of the circuit. A shock, possibly lethal, is likely to result from these conditions; RCDs are designed to disconnect quickly enough to prevent such shocks. In the United States and Canada, a residual current device is also known as a Ground Fault Circuit Interrupter (GFCI) or an Appliance Leakage Current Interrupter (ALCI).

RCDs operate by measuring the current balance between two conductors using a differential current transformer, and opening the device's contacts if there is a balance fault (i.e. a difference in current between the phase conductor and the neutral conductor). More generally (single phase, three phase, etc.) RCDs operate by detecting a nonzero sum of currents, i.e. the current in the "hot" or "hots" plus that in the "neutral" must equal zero (within some small tolerance), otherwise there is a leakage of current to somewhere else (to ground, or to another circuit, etc.). The National Electrical Code, which is the enforcable code in most of the United States, requires GFCI devices intended to protect people to interrupt the circuit if the leakage current exceeds a range of 4 to 6 milliamps of current (the exact trip setting can be chosen by the manufacturer of the device and is typically 5 milliamps) within 25 milliseconds. GFCI devices which protect equipment (not people) are allowed to trip as high as 30 milliamps of current. RCDs are designed to prevent electrocution by detecting the leakage current, which can be far smaller (typically 5- 6 mill amperes) than the trigger currents needed to operate conventional circuit breakers, which are typically measured in amperes. RCDs are intended to operate within 25 milliseconds, before electric shock can drive the heart into ventricular fibrillation, the most common cause of death through electric shock.

These values were set by tests at Underwriters Laboratories during which volunteers were subjected to shocks of known amperage and voltage. Initially, the GFCI